# FARM SOILS
## THEIR MANAGEMENT AND FERTILIZATION

EDMUND L. WORTHEN

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THE WILEY FARM SERIES

EDITED BY

A. K. GETMAN

CHIEF, AGRICULTURAL EDUCATION BUREAU, NEW YORK STATE DEPARTMENT OF EDUCATION

AND

C. E. LADD

DEAN, NEW YORK STATE COLLEGE OF AGRICULTURE

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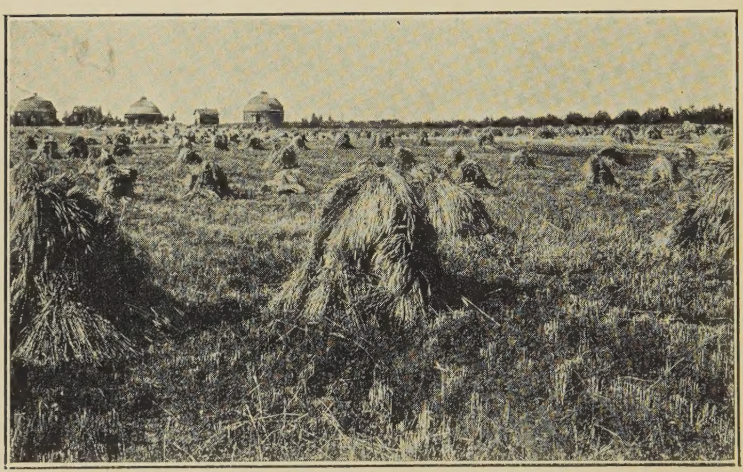

*Frontispiece*

A PRODUCTIVE SOIL. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Ultimate success in farming can be achieved only where the productiveness of the soil is fully maintained.

# FARM SOILS

## THEIR MANAGEMENT AND FERTILIZATION

BY

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*at Cornell University*

*THIRD EDITION*

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# PREFACE

Efficient soil management is essential to profitable crop production, and effective soil conservation is a prerequisite of a permanent agriculture. Many fail to achieve success in farming because of their inability to establish soil-management practices which will insure the economic production of crops without depleting the soil on which they are produced.

The soil is a highly variable and complex medium, and for its efficient management and conservation one must take into consideration various chemical, biological, and physical properties which are extremely technical in character. However, without mastering such technical details, one may develop practical systems of soil management which will insure good yields without soil depletion.

"Farm Soils" has been written for farmers and for students who are primarily concerned with the problems of practical soil management. As stated in the preface of the first edition, emphasis is placed on what to do and when and how to do it. At the end of each chapter under "General Information" is assembled the information justifying the practices; that is, why certain things should be done. Although this material is not essential to the successful establishment of an efficient system of soil management, the author believes that both farmers and students will be interested in the *why*, as well as the *how* and *when*, of various practices essential to the management and conservation of agricultural soils.

In organizing the contents special consideration has been given to soil-management problems as encountered by the farmer while at work in the field or while planning his farm business. All phases of soil management are treated insofar as they bear on the economic production of crops and on the permanency of the soil itself. Specific instructions are given for draining and tilling soils, for controlling erosion, and, somewhat more briefly, for irrigating land and practicing dry-land farming. Special emphasis is placed on such fertility practices as manuring, liming, fertilizing, and growing soil-improving crops. Careful attention has been paid to connecting recommended soil practices with specific crop practices. For example, special chapters have been devoted to managing field soils, pasture soils, garden and lawn soils, and fruit soils.

During the five-year period, since the writing of the second edition, experimental and research studies on soil problems have produced new information justifying certain modifications in soil-management practices. Field demonstrations and the experiences of successful farmers during this period have also supplied additional information which has warranted some changes in recommended practices.

It is the hope of the author and editors that this third edition will prove of even greater value than the former two editions for use both on the farm and in the classroom.

THE AUTHOR AND EDITORS

JANUARY, 1941

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# FARM SOILS

## CHAPTER I

## SELECTING THE SOIL AND PLANNING ITS MANAGEMENT

A productive soil is the first essential for profitable farming. Crop yields well above the average must be secured before farming becomes attractive as a business. When a farm soil is first cropped, good yields may often be obtained without any treatment other than thorough cultivation. With continued cropping, yields are reduced unless provision is made for returning to the soil certain plant nutrients which the crops require. Soils frequently become depleted; crop yields are then so reduced that farming fails to pay; and ultimately, the farm is abandoned or taken over by someone capable of establishing a soil-improving system of management.

FIG. 1. AN ABANDONED FARM. (Agronomy Dept., N. Y. State Col. of Agr.)

Soils frequently become depleted, and ultimately the farm is abandoned.

Soils vary in their capacity to produce crops. Some never were and never will be fit for profitable farming; others, good in the beginning, have been impoverished by soil-depleting practices; still others, poor to start with, have been made fertile by efficient management. Every progressive farmer is interested in the fertility of his soil, for he realizes that the continued successful production of crops requires the maintenance of a high-fertility level of the soil. Soil conservation is essential to continued rural prosperity.

FIG. 2. SUBMARGINAL LAND.

Soils which for one reason or another cannot be economically farmed constitute a vast area of what is termed submarginal land.

Land utilization as a state and national problem has received little consideration until recent years. The responsibility for the use of land has been left largely to the individual farmer. As a result, during periods of agricultural prosperity, soils poorly suited to profitable farming have been brought into production. In some instances the topography was too rough or the surface too stony for economic tillage;

in others, the rainfall inadequate or the soil itself incapable of retaining moisture sufficient for good crop yields; or in still other instances, the soil has been so susceptible to water or wind erosion that the cost of erosion control was prohibitive. Other reasons for the failure of farm lands to return a profit are: shallow surface soils deficient in organic matter; high acidity; impervious or extremely acid subsoils; and excess alkali. Unfortunately, many soils which with proper management would today be capable of maintaining a profitable agriculture have, as a result of careless handling, become so depleted in fertility or so badly eroded that they are no longer suited to cropping. Those soils which for one reason or another cannot be economically farmed constitute a vast area of what is termed *submarginal land*. A sound public land-utilization program is essential not only for the economic use of marginal and submarginal lands, but also for the preservation of the soil of farms which are today being operated with profit.

FIG. 3. GOOD FARM BUILDINGS.

Farm buildings and other improvements are factors of importance in the selection of a farm.

There are certain essentials, other than the soil, that should be considered in selecting the farm. Attention should be given to the location from the standpoint of climatic conditions and marketing facilities. The nature of the roads, farm buildings, and other improvements are all factors of importance. Buildings can usually be purchased with a farm cheaper than they can be built. One should make certain that the community is a desirable one in which to live, with satisfactory school and church facilities, and with progressive and reasonably prosperous farmers as neighbors. It should be remembered that a good farm is generally a better buy than a poor one.

Before buying a farm one should consult the county agricultural agent. He is familiar with the agricultural and soil conditions in his local county and is in a position to furnish helpful suggestions as to locations suited to the different types of farming. One should write to his state agricultural college requesting a copy of any available printed information dealing with the selection and purchase of farm land. Furnish the institution with information as to the type of farming you purpose to follow and the capital available; for with this information supplied, the agricultural workers can supply worth-while general information about the section of the state in which a suitable farm may be located.

**Operations:**

1. Selecting the soil.
2. Managing the soil.

## 1. SELECTING THE SOIL

Even where other conditions are favorable, the character of the soil must be considered; for a good soil, adapted to the type of farming to be followed, is a prime essential to success. A poor soil may be made productive, but the process is a slow and expensive one. A knowledge of certain factors in soil management and their relation to crop production is necessary in selecting farm land.

**Factors to be considered:**

A. Topography and drainage.
B. Surface soil.
C. Subsoil.
D. Chemical composition.
E. Vegetative growth.
F. Soil-survey and land-use reports.

**A. Topography and drainage.** Rough land is expensive to till because field operations cannot be performed economically upon it. Where the land is rough, the fields are necessarily irregular in shape and subject to erosion. In some instances attempts are made to farm land so hilly that it should never have been cleared, while in other instances tillage is attempted on rough areas which at best are adapted only to permanent pasture and grass meadows. A relatively level to gently rolling topography is essential for the economic production of crops requiring tillage.

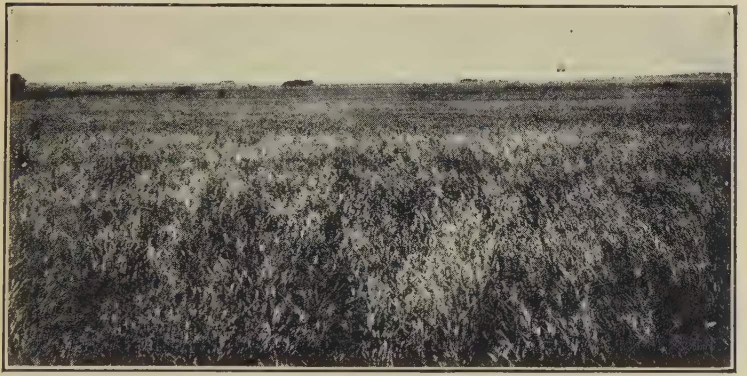

FIG. 4. FAVORABLE TOPOGRAPHY FOR FARMING.

A relatively level to gently rolling topography is essential for the economic production of crops requiring tillage.

Choose a soil that is naturally well drained or one that has been or can be adequately tiled. If there is a drainage system be sure that it has been so installed that permanency is assured. When poorly drained land is considered, take into account the expenditure of both money and labor required to install an efficient drainage system.

**B. Surface soil.** The surface soil should be deep, friable, and well supplied with organic matter. It should be free from stones large enough to interfere with tillage operations. The topography, size and shape of fields, and physical soil conditions should be favorable for the use of power machinery. The depth of the surface soil is important since crops are largely dependent on surface soil for plant-food [1] other than that supplied by the atmosphere. A depth of 8 to 10 inches is very desirable, and 12 to 14 inches is even better.

Fig 5. Corn Field in the Corn Belt.

Crops vary in their adaptation to soils. Grain and grass crops grow best on a moderately heavy soil.

A soil may be so heavy that it is difficult to farm. Because of the high content of clay, such a soil is extremely sticky when wet, and upon drying forms hard clods. Another soil may contain so much sand or gravel that it dries very rapidly, has a low water-holding capacity, and its crops suffer in dry seasons. Large stones also may present a difficulty in tilling the soil. It is highly desirable that a soil contain such an admixture of sand, clay, and particles of other sizes that it tills easily, dries promptly after rains, and at the same time holds water so well that crop growth is not seriously checked in dry periods.[2]

---

[1] Technically the term *plant-food* refers to the organic plant-growth-promoting substances, such as starch and the sugars. In practical agricultural literature the term is commonly used to refer to any chemical element, or its compounds, used by plants. The term is used in the broader sense in this book.

Crops vary in their adaptation to soils. Grain and grass crops grow best on a moderately heavy soil. Vegetable crops require a soil of a lighter texture. For early vegetables, a light, sandy loam surface soil is best. Celery, onions, and lettuce are adapted to muck and peat soils. Of the fruits, apples and pears do best on relatively heavy soils while peaches and citrus fruits prefer a soil somewhat sandy in character. Good natural drainage to a depth of 10 feet or more is essential for the tree fruits.

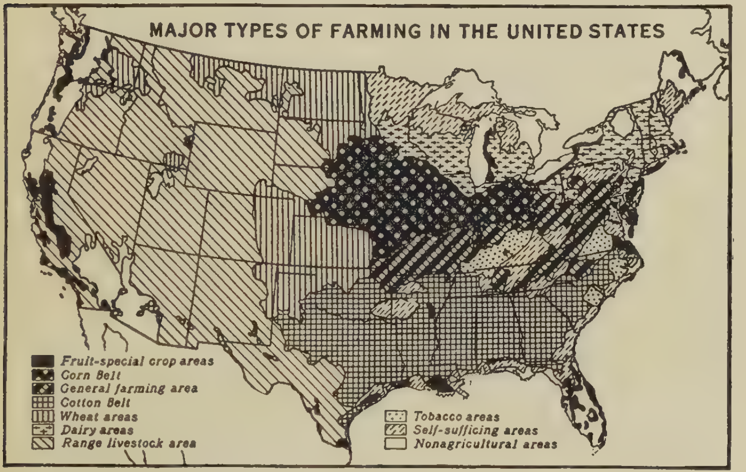

FIG. 6.

The general location of the more important types of farming is shown in Fig. 6.

Select a soil free from large stones and with a surface soil well supplied with organic matter to a depth of at least 8 inches. Consider the texture of this surface material and make certain that it fulfills the requirements of the crops to be grown.

---

[2] See General Information at end of chapter for soil texture, structure, and other physical properties, as well as for the classification and naming of soils.

**C. Subsoil.** The subsoil also requires consideration. Not infrequently the productiveness of a soil is impaired by an unfavorable subsoil. Avoid subsoils that are so heavy as to be impervious to the movement of water. Where they occur the drainage is invariably poor, and crops cannot develop a root system to a normal depth. Subsoils of a very sandy or gravelly character are also objectionable because they drain too rapidly and their crops suffer in dry seasons. A reasonably heavy loam, silt loam, or clay loam of a yellowish to reddish color forms the most desirable subsoil. Particularly objectionable is an impervious condition termed *hardpan* which sometimes occurs in the subsoil. A true hardpan is formed by the

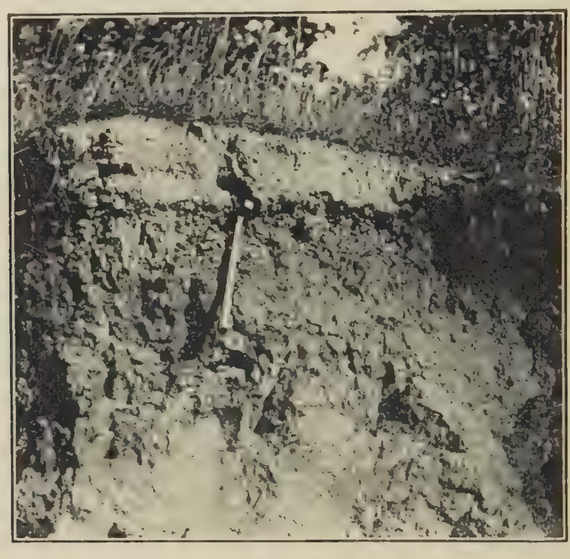

FIG. 7. AN IMPERVIOUS SUBSOIL.

Avoid subsoils which are so heavy as to be impervious to the movement of water.

cementing together of the soil grains into a hard stone-like mass. A more common condition is an impervious layer in the subsoil caused by the pore spaces' becoming filled with fine clay particles. Such "tight-clay" subsoils, called *clay-pans,* are generally associated with an extremely acid condition, so that from both the physical and the chemical standpoint they are objectionable.

In arid regions subsoils frequently contain injurious amounts of soluble salts, while in other sections bed rock may occur so near the surface that crops suffer in dry seasons. Failure to give adequate consideration to subsoil conditions frequently results in the improper evaluation of farm land.

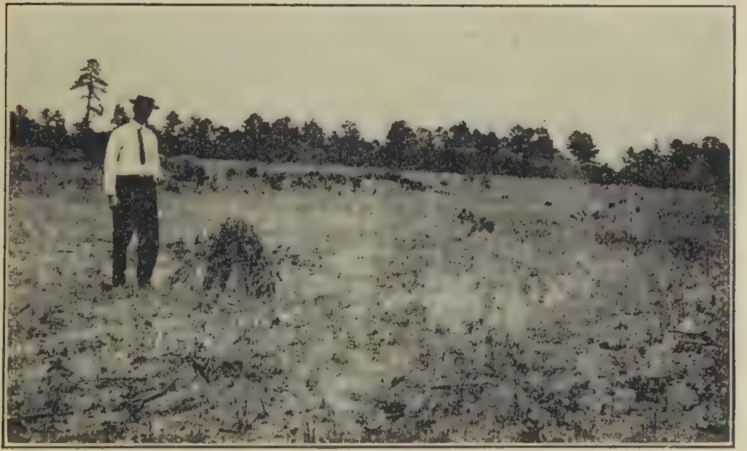

FIG. 8. AN UNPRODUCTIVE SOIL.

A soil should be well supplied with plant-food.

**D. Chemical composition.** A soil should be well supplied with plant-food. The nitrogen is largely in the surface soil, the amount depending on the organic-matter supply. The mineral plant-foods should occur in fair amounts, though a deficiency can be supplied economically by artificial fertilization. It is more important to make certain of a good supply of plant-food when selecting a soil for the production of field crops than it is for vegetables or fruit. For vegetables or other high-value crops, any of the plant-foods furnished by fertilizer can be supplied profitably if they are deficient. The yield of fruit is seldom dependent on the supply of plant-food other than nitrogen. This can be advantageously furnished as a nitrogenous fertilizer material or secured through legume cover crops or farm manure. However, cover crops will often require plant-food other than nitrogen, and sometimes lime in addition. With field crops the margin of profit is at best small, and expensive fertilizer applications cannot be made with profit. It is essential that the surface soil be adequately supplied with organic matter, and highly desirable that the subsoil be so well supplied with lime as not to be highly acid in character. An extremely acid surface soil will necessitate the purchase of lime for the legumes which should be grown in rotation with the grain, silage, and fiber crops;

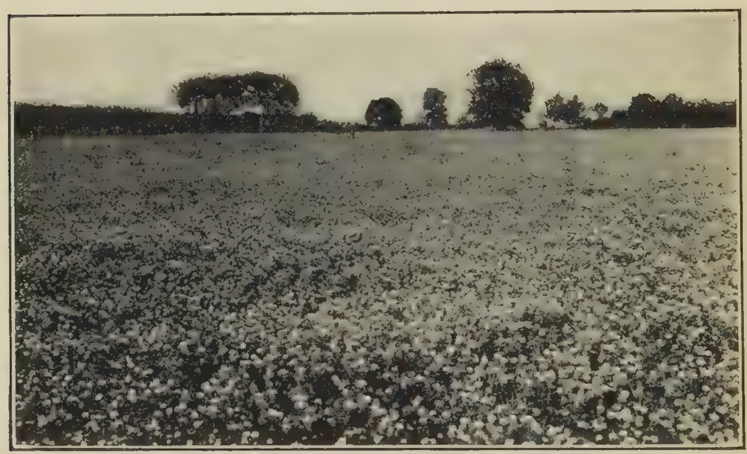

Fig. 9. A Field of Good Clover.

The character and vigor of the vegetation are good criteria of the productivity of a soil. In selecting a soil pay particular attention to the growth of such legumes as clover and alfalfa in grain and livestock sections.

but this defect can be remedied and the soil made suitable for the legumes, provided the subsoil is not too acid. Acidity of the surface soil reduces the value to the extent of the cost of the lime required to neutralize it; a lime deficiency in the subsoil is a defect which cannot be remedied by any known practical method of treatment.[3]

**E. Vegetative growth.** The character and vigor of the vegetation are good criteria of the productivity of a soil. In selecting a soil in improved agricultural sections, determine the growth and yield of the crops grown locally. Pay particular attention to the growth of such legumes as clover and alfalfa in grain and livestock sections. Take into consideration the seasonal conditions, for when they are especially favorable even poor soils yield well. Also take into consideration the soil treatment that has been given, for a good yield can be secured on practically any agricultural soil with adequate applications of lime, manure, and fertilizers. Yields may be good but may be unprofitable nevertheless, owing to the cost of the treatment applied. At such times the yield would certainly be misleading as a measure of the true productiveness of the soil. On livestock farms, it is well to ascertain the number of animals which the farm has supported and the normal expenditure for purchased feed.

Much can be learned about the value of soils by studying the character of the natural vegetation. Areas that were originally prairie have a good supply of organic matter in the surface soil. Timbered land, on the other hand, is less well supplied with this valuable constituent. The productivity of timbered soils varies with the kind and growth of trees. Where black walnut, American elm, hard maple, and ash dominate and have made a good growth, the soil is invariably productive and not greatly deficient in lime. The hardwoods, such as oak and hickory, indicate a somewhat less productive soil, though where the growth is vigorous a fairly productive soil may be expected. It may be somewhat acid in character and poorly supplied with organic matter. Where scrub oak, post oak, or black jack oak dominate the timber growth, the soil will invariably be found unproductive. This character of timber growth is dominant on the uncleared areas of poor soils in the southern states. Pine and chestnut may grow vigorously on extremely poor soils. The former is adapted to sandy soils, while the latter grows naturally on soils extremely deficient in lime.

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[3] See General Information at end of chapter for chemical essentials of plant growth and plant-food supply of soils.

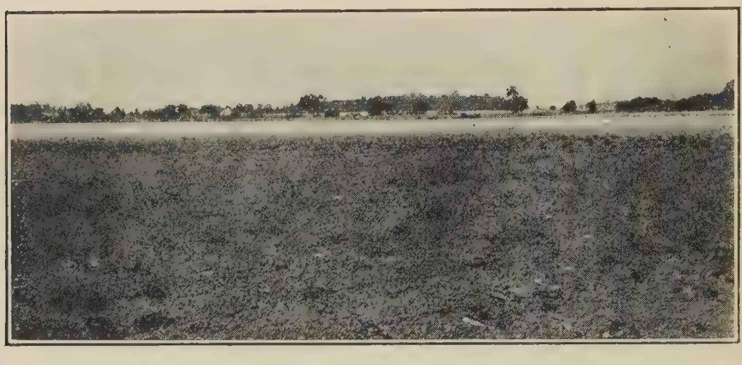

FIG. 10. A BOUNDARY LINE BETWEEN PRAIRIE AND TIMBER SOILS.

Dark-brown prairie soil in foreground; gray timber soil in background. Areas which were originally prairie have a good supply of organic matter in the surface soil. Timbered land, on the other hand, is less well supplied with this valuable constituent.

Weeds and other wild vegetation also indicate the productivity of the soil. Where sweet clover grows wild or where wild white clover and Kentucky bluegrass dominate in native pastures, the soil is never extremely acid and is generally above the average in productivity. Sorrel, paint brush, redtop, broom sedge, and poverty grass are examples of vegetative growth indicative of poor soil of an acid character; Jimson weed, button weed, smart weed, and rough pigweed grow vigorously only on good soil.

In selecting a soil one should make certain that the surface soil is not infested with noxious weeds or seed of such weeds.

The weeds to guard against vary in the different sections of the country. Especially objectionable because of difficulty of eradication are quack grass, wild mustard, sow thistle, garlic, and morning glory. Livestock farms are more often weedy than are cash crop farms. The less troublesome weeds may be eradicated by thorough tillage and proper cropping systems.[4]

**F. Soil-survey and land-use reports.** Utilize the reports and soil maps of areas covered by soil surveys, where these are available. These reports give much valuable information as to soil characteristics, crop adaptation, and value of farm land. In addition, they include a summary of the climatic conditions and the agricultural history of the section which they cover. Certain of the state soil survey reports include valuable information relative to the fertilization and cropping of the different soils. Land-classification maps and land-use reports have been prepared by some states, and other states have made similar information available in connection with their rural-zoning program. In selecting a farm all available information of this nature should be used.

## 2. Managing the Soil

After a farm has been secured, work out a definite plan of soil management.

**Procedure:**

A. Control the water supply.
B. Prevent erosion.
C. Give the soil good tillage.
D. Replenish organic matter.
E. Conserve farm manure.
F. Apply lime to acid soils.
G. Use commercial fertilizer.
H. Maintain conditions favorable for beneficial soil organisms.
I. Secure good yields and provide for permanence.

---

[4] See "Crop Production and Management," by Joseph F. Cox, published by John Wiley & Sons, for information concerning weeds and their eradication.

**A. Control the water supply.** A well-drained soil is essential in the production of the common farm crops. Unless the soil is naturally well drained, artificial drainage must be installed before good yields can be secured. There are several methods of draining land. Of these, the tile-drainage system is the best under most conditions.

In dry regions the growth of crops is often controlled by insufficient rainfall. Here, either through the practice of "dry-land farming" or by means of irrigation, the required moisture is furnished. In such dry sections, the salt content of the soil frequently becomes so high that crops are injured. This excessively high salt content produces what is known as an *alkali soil.*

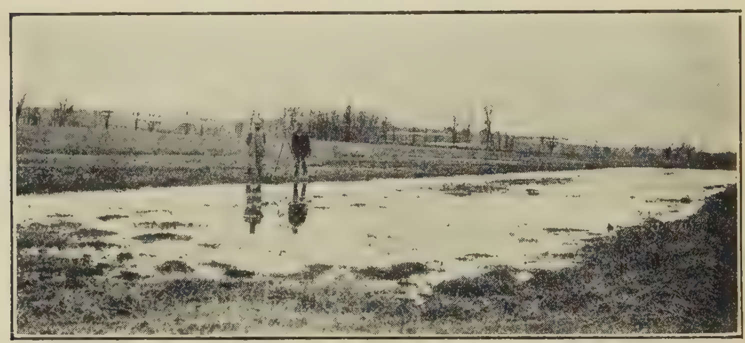

FIG. 11. A POORLY DRAINED FIELD. (Agronomy Dept., N. Y. State Col. of Agr.)

Unless the soil is naturally well drained, artificial drainage must be installed before good yields can be secured.

**B. Prevent erosion.** The failure to control erosion has resulted in the enforced abandonment of many farms. It has also reduced crop yields on areas that are still being farmed with profit. Erosion may develop so slowly that its injurious effect is not recognized until serious damage has been done. This is especially true of what is known as sheet erosion.[5]

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[5] See page 139 for explanation of kinds of erosion.

Although soil erosion may not be completely prevented, it is essential that the surface soil be retained and not be permitted to wash either to the lower parts of the fields or into streams. Frequently precautions must be taken to prevent erosion even on comparatively level land.

Wind erosion is most severe in the prairie regions, especially during periods of serious drought. The so-called "dust bowl" is the result of destroying the prairie-sod covering, either by plowing or overgrazing, in a section subject to serious wind erosion. The problem of wind-erosion control is not confined to arid regions, however. With light sandy soils, and muck or peat land in the hunid sections, provision must often be made to prevent the loss of surface soil as the result of wind.

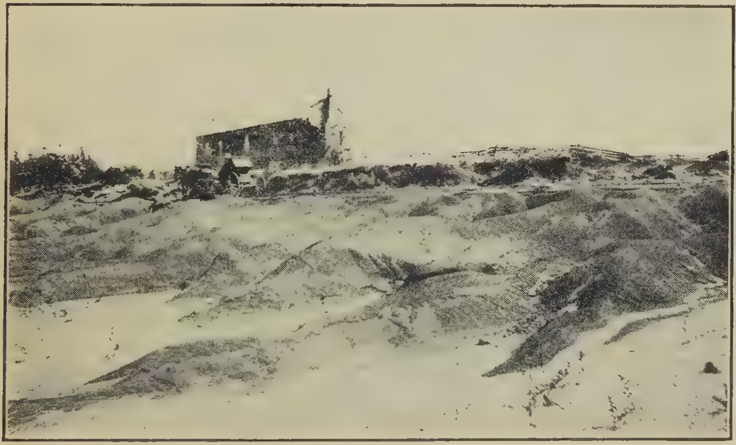

FIG. 12. SOIL EROSION.

The failure to control erosion has resulted in the enforced abandonment of many farms.

**C. Give the soil good tillage.** Thorough tillage is essential for good yields of field and garden crops. A poorly prepared seed-bed has often been responsible for a low yield. Among the various farm operations, time is seldom spent to better advantage than in plowing and fitting the seed-bed. Of equal importance for the cultivated crops is thorough and proper cultivation during the early stages of growth. Frequent, shallow cultivation has been found most effective. Weeds are serious competitors of crops, and cultivation is one means of keeping them in check. There is no known fertilizer or other soil treatment that will take the place of good tillage.

**D. Replenish organic matter.** Organic matter [6] is an essential constituent of agricultural soils. Their productivity is to a large extent dependent on it. So long as a soil is adequately supplied with fresh organic matter, good yields can be secured with comparatively inexpensive soil treatment.

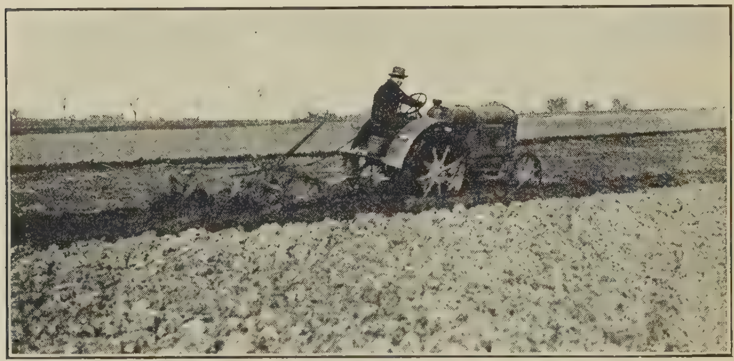

FIG. 13. PLOWING.

Time is seldom spent to better advantage than in plowing and fitting the seed-bed.

Under natural conditions the organic-matter content of the soil is at least maintained and often increased. In draining and tilling the soil, man starts destructive processes. These operations may be absolutely essential in the utilization of the soil; but, since they enable plants to secure the soil nutrients more rapidly, through increasing the rate at which these nutrients become available, they hasten soil depletion. A poorly drained soil is in an ideal condition for the accumulation of large amounts of organic matter. As a result, such soils are commonly dark in color. Upon draining, air replaces the water removed, and the rate of decomposition of the organic matter is increased. Tillage incorporates additional air in the stirred soil, with the result that decomposition proceeds more rapidly. Consequently, when a soil is put into cultivation, it becomes necessary to make provision for maintaining the organic matter. Otherwise, profitable production would at best be temporary; and the farmer can ill afford to overlook permanence in his business.

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[6] See page 28 for description of the term *organic matter.*

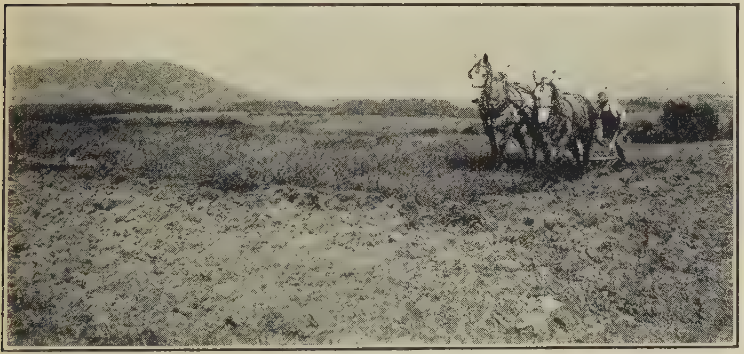

FIG. 14. PLOWING UNDER SOD.

It becomes necessary to make provision for maintaining the organic matter.

Since cultivation is destructive of soil organic matter, tilled crops, such as corn and cotton, should not be grown continuously on the same land. Hay and pasture crops, brought into the rotation, help to maintain the supply of organic matter. Crop residues, such as corn stover and straw, should be returned to the soil; or else they should be utilized as feed or bedding for livestock, and the manure applied to the land. Green-manure crops and catch crops may often be grown to advantage and plowed under as a source of organic matter.

The replenishing of soil organic matter is costly. In the intensive production of high-value crops one may justify the necessary expenditure to maintain a high-organic matter level of the soil; but where low-value crops are grown, the replenishing of organic matter must be restricted to the less costly methods. Consequently, the soil organic-matter level which can be maintained profitably will depend largely on the intensity of cropping and the value of the crops grown. As a long-time problem in efficient soil management, the maintenance of an organic-matter level favorable for economic production of crops is one of the most baffling of the problems in the practical management of farm soils.

**E. Conserve farm manure.** Farm manure is a highly valuable by-product of the farm. It is an important source of organic matter and of available plant-food as well. More and more are farmers appreciating its fertilizing value. Nevertheless, many of them, through permitting the manure to accumulate in the open barnlot, lose enormous amounts of valuable plant-food. The proper handling and the wise use of the farm-manure supply are essential on any well-managed farm. Farms well stocked with domestic animals and on which the manure is well cared for usually have fertile soil with accompanying high crop yields.

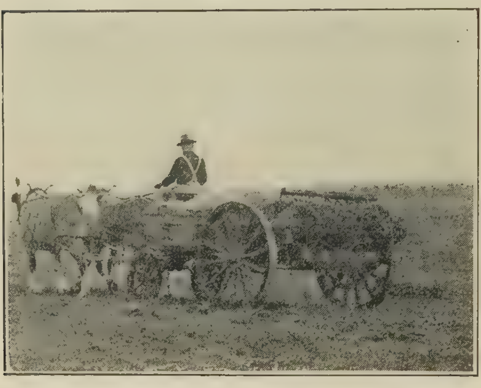

FIG. 15. SPREADING FARM MANURE. (Agronomy Dept., N. Y. State Col. of Agr.)

The proper handling and the wise use of the farm-manure supply are essential on any well-managed farm.

**F. Apply lime to acid soils.** Farmed soils tend to become acid. Most crops grow best in soils that are slightly acid, but some crops, such as red clover and alfalfa, require a neutral soil or one very slightly acid. Soils may become so acid that practically none of the common agricultural crops will make a normal growth. Occasionally nature has supplied a soil so abundantly with lime that it can be farmed for many years without becoming acid. Over much of the territory east of the Mississippi River there is a distinct need for lime. Here red clover and alfalfa will not grow until the soil is limed. Even in the territory west of the Mississippi an inadequate lime content of the soil may influence the yield of certain lime-loving crops. Where soils are acid, lime is essential for successful farming.

FIG. 16. APPLYING LIME. (Agronomy Dept., N. Y. State Col. of Agr.)

Where soils are acid, lime is essential for successful farming.

**G. Use commercial fertilizer.** Adequate drainage, erosion control, good tillage, and crop rotation, along with lime when needed and the replenishing of soil organic matter, will not necessarily assure satisfactory crop yields. These important practices will invariably have to be supplemented by the use of commercial fertilizers. Crops, like animals, must be adequately nourished for best growth. Even though profitable farming requires first of all that the necessary nutrients for crops be supplied so far as possible by the soil and through farm-produced materials, nevertheless plant-food must be purchased to some extent in the form of manufactured fertilizers. In order to appreciate the fertilizer problem and to develop adequate fertilizer practices on the farm, one must understand the fundamentals of fertilizer chemistry and the importance of maintaining the plant-food supply of the soil.[7]

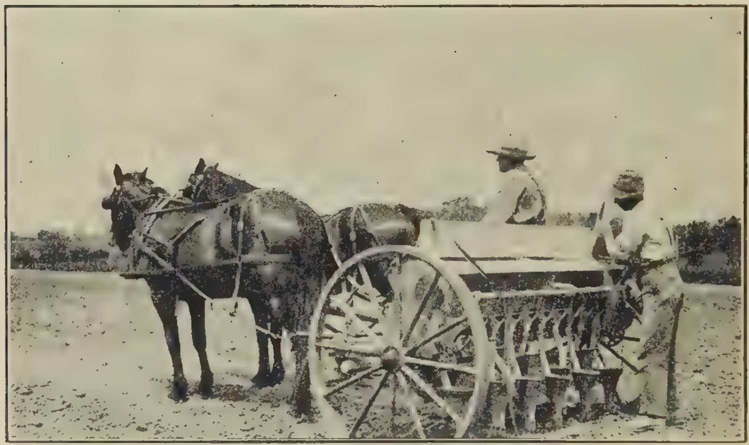

Fig. 17. Applying Fertilizer.

**Plant-food must be purchased to some extent in the form of manufactured fertilizers.**

The extent to which the purchase of fertilizer can be justified depends on the value of the crop increases produced by the fertilizer in comparison with its cost. Crops of high value, such as most vegetables, flowers, and tobacco, may be heavily fertilized with profit. The low-value crops, such as grain and hay, will not justify a large expenditure for fertilizer. In general, on high-value land a larger investment in fertilizer can be justified than on low-value land. Also, in some types of farming, it is practical to supply more nutrients from farm-produced materials than it is in other types. For example, in livestock farming, considerable amounts of the plant-food removed in crops can be returned to the soil in the manure produced by the animals. In grain production, even where little livestock is kept, legume crops may be grown in rotation with the grain as a means of utilizing atmospheric nitrogen. On the other hand, in the production of high-value cash crops, especially on high-priced land, one is not justified in sacrificing a cash crop in order to produce a soil-improving crop. Soil-improving catch crops or winter cover crops may sometimes be justified, but to a very large extent the nutrients can be supplied more economically in the form of purchased fertilizer.

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[7] See General Information at end of chapter for chemical essentials of plant growth and for the plant-food supply of soils.

Because of the great variation in the returns from fertilizer, depending largely on the value of the crop produced, there have developed two rather distinct systems of fertilization. One is called the *mineral system,* and the other the *complete fertilizer system.*

*The mineral system.* In this system suited primarily to the fertilization of low-value crops, the nitrogen is supplied largely through the growing of legume crops, or through the application of farm manure, or often through the combination of the two processes. Where most of the crops are fed to livestock, considerable amounts of potash and some phosphorus, in addition to nitrogen, are returned to the soil. The mineral element phosphorus, and to a somewhat lesser extent potassium, must be supplied in the form of fertilizer.

*The complete fertilizer system.* This system suited to the fertilization of high-value crops includes, in addition to the application of the two mineral nutrients, the application of considerable amounts of fertilizer nitrogen. In general, it also provides for a much heavier rate of application of fertilizer. In both systems lime should be applied in amounts to maintain the soil reaction at a point favorable for the crops grown.

The character of the fertilizer, as well as the amount required in either system but especially in the latter, should be modified to a greater or lesser extent, depending on soil conditions. Soils deficient in organic matter, especially when sandy in character, require more nitrogen and usually more potash than do heavy soils. Muck and peat soils are better supplied with nitrogen than are most mineral soils, but are in greater need of potash. Consequently, in their fertilization, potash becomes of equal or sometimes of even greater importance than phosphorus, and nitrogen of relatively less importance, especially on newly farmed muck and peat.

It is also well to appreciate that fertilizers become less essential as the annual rainfall becomes less. Their use on field soils is largely confined to the area east of the Mississippi River. By far the greatest tonnage is used in the states from Virginia on the northeast to Mississippi on the southwest. In the northeastern and central western states large amounts are applied for vegetables and other intensively produced cash crops. The use of mineral fertilizers, especially phosphorus for soil-improving crops, has been greatly stimulated by the Agricultural Conservation Program.

**H. Maintain conditions favorable for soil organisms.** A soil to be productive must contain certain beneficial organisms, and for normal crop growth others that are injurious in their effect on plants must be kept under control. These organisms vary in size from the rodents, insects, worms, and slugs to the minute microscopic forms of animal and plant life. It is especially the microscopic forms which play such an important part in activities within the soil and liberate nutrients in forms usable by plants. Their activities make certain those changes in soil composition that are termed *biochemical changes.*

The development of bacteriology and biochemistry has contributed greatly to the solving of many intricate problems associated with soil fertility and the growth of plants. As the result of the development of practical methods of utilizing more efficiently the beneficial activities of microscopic soil organisms, the development of permanent systems of agriculture has been made possible. An understanding of the functions of soil organisms, and of their efficient utilization in practical soil management, is essential to a prosperous and permanent agriculture.[8]

FIG. 18. A GOOD FIELD OF OATS;

High yields and low-production costs are recognized essentials of profitable farming.

**I. Secure good yields and provide for permanence.** High yields and low production costs are recognized essentials of profitable farming. Proper manipulation and adequate treatment must be given the soil before large crop yields can be secured. Even though prices of individual crops are frequently low because of overproduction, the farmer must necessarily strive to secure good yields.

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[8] See page 31 for description and discussion of the activities of soil organisms.

During the First World War a serious food shortage developed. The American farmer was told that the winning of the War depended largely on his ability to produce adequate amounts of food products. During the post-war depression much was said about overproduction. The low prices which prevailed on agricultural products during this period were accounted for by the low price level on all commodities rather than by general overproduction of agricultural products.

The individual farmer has nothing to gain by reducing yields unless lower yields represent lower unit costs. Irrespective of economic conditions, good yields can be justified on every acre that is farmed. History tells of the severe famines and pestilences resulting from an inadequate food supply, which have occurred in every stage of man's development. Future generations will, in all probability, be confronted by an ever-increasing food problem.

The farmer of today should appreciate the responsibility of land ownership. The soil is a natural asset which should be conserved. It should be utilized as a source of food and clothing for the present generation without lessening its value to future generations. Profitable farming should never become dependent upon soil exhaustion. America must develop an agriculture which will offer an attractive return from systems of soil management under which her soils will become more productive. It is only under such conditions that farms can be passed down from father to son through the generations in an ever-increasing state of fertility.

## GENERAL INFORMATION

### 1. The Make-Up of the Soil

**A. Rock material.** The soil, which consists, so far as the farmer is concerned, of the loose surface material of the earth's crust in which it is possible to produce agricultural crops, is composed of various materials. Rock particles varying in size constitute the greater part of most soils. These rock fragments have resulted from the weathering or breaking down of large rocks. This material makes up such a large part, by weight, of most soils that they may be considered as having been derived from rocks.

In some soils the individual particles of rock can be readily seen with the naked eye. Not infrequently large particles of undecomposed rock occur in fields in such numbers as to interfere with tillage operations. In some sections it has been necessary to pick the stone from the land before plowing was possible, and in the New England States fences built of stone picked from the enclosed fields are a common sight. Other soils are so fine in character that the individual particles cannot be seen, but when examined under

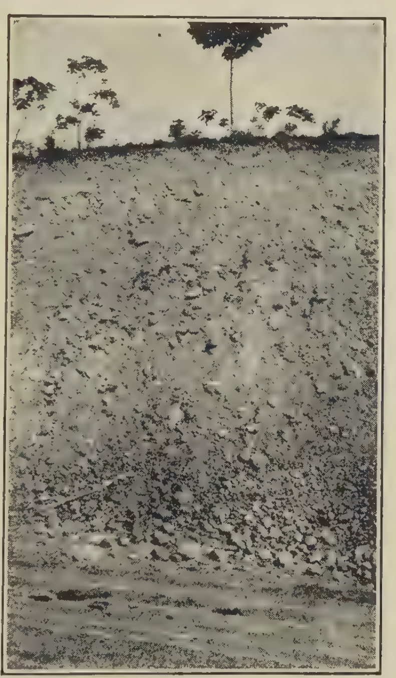

Fig. 19. Glacial Gravel.

Rock particles varying in size constitute the greater part of most soils.

a microscope the rock particles are largely discernible and look much like sand or fine gravel. Though these rock particles vary in size, they are an important soil constituent, and have a great influence on the productivity of most agricultural soils.

**B. Soil grains.** The individual rock particles of the soil are known as *soil grains.* Where the smaller soil grains are found joined together in groups they are called *granules.* Sometimes a number of small grains may accumulate around a large one to form a granule. The process by which the soil grains are joined together in groups is known as *granulation,* and a soil in which the process has developed is referred to as a *granulated soil,* or one having a *crumb structure.*

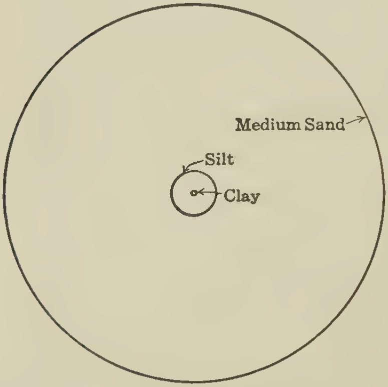

FIG. 20. RELATIVE SIZE OF CLAY, SILT, AND SAND.

Two hundred times maximum diameter. A circle 15.7 inches in diameter would represent the relative size of gravel.

These soil grains not only influence the physical properties of the soil, but they also furnish certain chemical elements essential for the growth of plants. Their ability to supply this plant-food in an available form is dependent on their further decay. The area of the surface of the soil grains is known as *grain surface.* A cubic inch of soil has from 50 to more than 1000 square feet of grain surface. Other things being equal, the greater the grain surface the more rapid will be the rate at which the mineral plant-food elements become available from the rock particles of the soil.

**C. Clay, silt, sand, and gravel.** Since the size of the soil grains influences the character and agricultural value of a soil, it has been found necessary to establish certain classes or grades based on size. The term *clay* has been given to the smallest grains. *Silt* includes the group next in size, then *sand,* and finally *gravel.* These groups may be further subdivided, but for all practical purposes the four classes—clay, silt, sand, and gravel—are all that need be considered. Their relative size is shown in Fig. 20.

**D. Heavy soils and light soils.** The terms heavy and light, applied to soils, do not refer to weight, but rather to the difficulty or ease with which the soils may be tilled. A soil containing a large proportion of clay grains is lighter in weight than one made up largely of sand, but on account of its sticky character it is spoken of as being *heavy;* whereas a sandy soil, because of the ease with which it can be tilled, is considered a *light soil.* The heaviness or lightness of a soil, then, depends upon the proportion of the different-sized grains—clay, silt, sand, and gravel—which the soil contains.

**E. Soil colloids.** The soil particles vary in their degree of decomposition as well as in their size and shape. As a result of the decomposition of rock particles and of organic matter, a jelly-like or colloidal product is formed. It constitutes the more finely disintegrated portion of the clay content. This material called *soil colloids* coats the individual soil grains and not only influences the physical condition of the soil, but also plays an intricate part in various chemical and biochemical changes which are constantly taking place in all agricultural soils. The sticky character of clay soils when wet, and the formation of clods on drying, are caused, or at least intensified, by this colloidal material. It has a great absorptive power not only for water, but also for substances in solution. The chemical changes resulting from this colloidal material are spoken of as *base exchange.*[9] Consequently, in addition to increasing the water-holding capacity of the soil, the colloidal material may perceptibly reduce the loss of nutrients by leaching. It is responsible for intricate chemical changes, some of which result in increased and others in decreased acidity, which influence the productivity of all agricultural soils.

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[9] See page 51 for explanation of *base exchange.*

**F. Organic matter.** Besides the rock particles, all agricultural soils contain plant and animal remains which constitute the soil *organic matter.* It is composed largely of vegetable material, since plants have contributed more than animals to its formation. As organic matter decomposes it forms a dark-brown to black substance known as *humus.* The term humus is often used interchangeably with organic matter, but it should be restricted to the old organic matter of the soil in which decomposition has progressed to the point where the cell structure of the plant and animal tissue has been destroyed. It can readily be seen that all humus is organic matter, but only thoroughly decomposed organic matter is true humus.

The organic matter, like the rock particles, influences both the physical and chemical properties of the soil. It is capable of absorbing several times its dry weight of water, and is influential in maintaining an adequate supply for plant growth. It loosens up heavy soils, thereby improving aeration and making them easier to handle, and at the same time makes light soils more firm and of much greater water-holding capacity. It may be beneficial in preventing the washing or erosion of the soil. The fresh organic matter decomposes very readily in a well-drained, cultivated soil, and furnishes large quantities of available plant-food, especially nitrogen, during the growing season of crops. It is the storehouse of the soil supply of nitrogen, and contains large amounts of carbon (about 10 parts carbon to 1 part nitrogen), and some phosphorus, potassium, sulfur, and iron. When decomposed to the form of humus, the carbon-nitrogen ratio is broadened to 20 parts carbon to 1 part nitrogen. Any of the chemical elements occurring in plants and animals may be expected to be found in the soil organic matter. It not only supplies the various plant nutrients, but also has been found to increase the rate at which plant-food becomes available from the soil grains.

While the fresh, active organic-matter content of a soil is an important criterion of its degree of fertility, an unproductive soil may contain a considerable quantity of humus, even enough to produce a dark color. Organic matter in the form of humus contains a smaller proportion of the more essential plant-food elements than does fresh organic matter, and is in such an advanced stage of decomposition that it is very ineffective. It is sometimes referred to as the inactive form of organic matter. It not only has little chemical effect, but it is less beneficial than fresh organic matter in improving the physical condition of the soil, or in stimulating activities of the beneficial soil organisms. When, as the result of a high humus content, the soil is dark in color, heat is absorbed more readily and the soil is warmer on sunny days, especially in the spring and fall, than is a lighter colored soil.

A soil that is well supplied with organic matter has a high buffering capacity; that is, it resists rapid changes in hydrogen-ion concentration. A crop will withstand greater soil acidity when the soil is well buffered. With a high soil organic-matter supply, crops will be injured less by toxic conditions resulting from residual effects of fertilizers, spray materials, or from other causes.

The fertility of farmed soils is closely related to the supply of organic matter. This organic matter is readily depleted through exhaustive cropping, and it has been found necessary to replenish the supply to prevent soil depletion. Replenishing soil organic matter is an important essential of efficient soil management.

**G. Surface soil and subsoil.** The organic matter of the soil is confined largely to the surface 8 to 12 inches. This darker topsoil, containing the organic matter is known as *surface soil;* the term *subsoil* is applied to the portion below, the character of which has been little influenced by organic material. Some surface soils have a depth of 18 to 20 inches, whereas others are only 5 or 6 inches deep. A deep, dark-colored surface soil is always desirable.

Since the color of the surface soil is influenced by the organic-matter content and its productivity is at least partly dependent on the same factor, there is a relation between soil color and productivity. Gray and yellow surface soils are deficient in organic matter, and consequently are low in natural productivity. Red surface soils are commonly somewhat more productive, but brown and black soils have the greatest natural fertility.

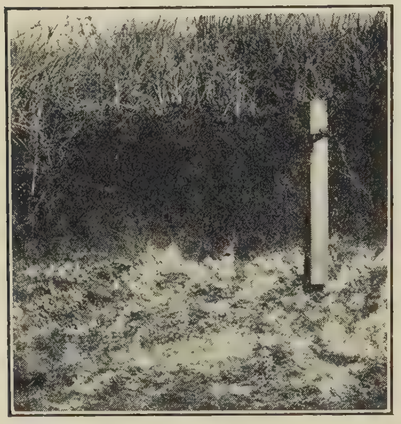

FIG. 21. SURFACE SOIL AND SUBSOIL.

This darker topsoil, containing the organic matter, is known as surface soil; the term subsoil is applied to that portion below, the character of which has been little influenced by organic material.

The subsoil, on account of its low content of organic matter, is commonly lighter in color than the surface soil and more compact in character. True subsoils are most commonly gray, yellow, or red, though not infrequently they consist of various mottlings of these three colors. Subsoil which contains a large proportion of clay particles may be very impervious to water, necessitating artificial drainage. A true hardpan, or even a well-developed claypan within 2 or 3 feet of the surface, always indicates a poor soil. In general, red and yellow subsoils indicate good drainage; gray and mottled ones, poor drainage.

**H. Soil air.** Regardless of how closely the soil grains seem to fit together, there is always open space between the various particles, irrespective of their size or character. In dry soil this space, often called *pore space,* is filled with air. The air circulates through the surface soil and subsoil, and the movement is called *aeration*. It has been found that in the ordinary plowed soil of a field half the volume is pore space and only half is occupied by particles of rock and organic matter. The air which circulates constantly through the soil is essential to plant growth. Like the soil grains and the soil organic matter, it plays its part in making possible the production of farm crops.

**I. Soil water.** Field soils always contain some water. This water occupies part of the pore space, replacing some of the air, though some of it occurs in the mineral and organic particles. Most of it occurs as a film, surrounding and clinging to the soil grains. Immediately following a rain, water may largely fill the pore spaces as it moves down through the soil.

Water has a threefold function in plant nutrition. (1) It furnishes plant-food, especially hydrogen; (2) it facilitates the nutrients' becoming available from the soil organic matter and rock particles, and transports these to the root system; and (3) it serves to transport from the soil and to diffuse throughout the plant the nutrients furnished by the soil. When insufficiently supplied with water, plants wilt, and during long-continued dry spells, crops are injured by drought.

Where the pore space of the soil is half filled with water, it has been found that the moisture is about right for good crop growth. Some soils require a higher moisture content than others; also, some crops grow well in a very wet soil, and others will withstand very severe droughts. Excess water in farmed soils may be removed by artificial drainage, and in very dry climates irrigation is resorted to as a means of furnishing an adequate supply of water for crop production.

**J. Soil organisms.** There is one other important constituent in farm soil. Without it the soil would remain a barren waste, for crops could not grow even with the proper proportions of soil grains, organic matter, air, and water. This fifth constituent is *soil organisms*. These consist, largely at least, of low forms of plant life, such as *bacteria* and *fungi* and associated microorganisms. The primary beneficial function of soil bacteria is the production of available plant-food for crops. They are essential for the decomposition of soil organic matter and for the liberation of its plant-food in a form that can be used again by new plants. They are instrumental in the breaking down of the rock material of the soil and in the liberation of its plant-food content. They also destroy residues which, if accumulated in large quantities in the soil, would have a toxic effect on plant growth. Certain of them are known to take the nitrogen from the air as it circulates through the soil and to make it available to legume crops.

The larger forms of soil organisms, including *rodents, insects, worms,* and *slugs,* are constantly moving and mixing considerable quantities of soil. Their activities may improve aeration and even the drainage of soils. Earthworms consume enormous quantities of soil. Passing through their bodies, the organic material, and to some extent the mineral material as well, is modified by the digestive action of the organism. The action of earthworms increases the availability of the nutrients, at least that of nitrogen occurring in the soil organic matter.

Microorganisms include certain low forms of animal as well as plant life. The terms *fauna* and *flora* are sometimes applied to soil organisms. Of the low forms of animal life the *nematodes* and *Protozoa* are of most importance. The former are worm-like in character, but largely microscopic in size. They subsist largely on the organic matter, but some feed on other forms of animal life, or on plant life in the soil; and still others penetrate roots and secure their nourishment from them, often causing considerable damage to the plant. The Protozoa are of single-cell structure and represent the lowest known form of animal life. Like nematodes they feed largely on organic matter, but in addition are believed to utilize, to some extent at least, soil bacteria as food. Under certain conditions their destruction of beneficial bacteria may result in injury to the soil. Protozoa are of no known benefit to soils.

*Fungi* are another group of soil organisms which are largely microscopic in size. They are thread-like in structure and like bacteria function in organic-matter decomposition. They are more tolerant than bacteria to acidity and, in very acid soils, may contribute more than bacteria to the decomposition of the organic matter.

*Actinomyces* constitute still another group of microscopic organisms which may be present in soils. They, too, decompose soil organic matter and appear to be of special value in breaking down humus and liberating nitrogen for the use of plants. Like true bacteria, actinomyces are not tolerant to much acidity, and are largely inactive where the soil reaction is below 6 *p*H. Scab, a common disease of potatoes, is caused by this organism, and one important factor in its control is soil acidification to 5.4 *p*H or below.

The true bacteria are credited with benefiting the soil in several ways. They decompose organic matter producing nitrates. This process is commonly referred to as *nitrification.*[10] They are essential also for the production of sulfates from the more complicated and less soluble forms. It is in the form of sulfates that plants utilize sulfur.

The other great beneficial function of bacteria is in the fixation of atmospheric nitrogen. Some function in the nodules on the roots of legumes, and others of less importance fix atmospheric nitrogen independently of legumes.[11]

Soil organisms are not all beneficial to the growth of plants. They are the cause of potato scab, root rots, wilts, the damping-off of seedling plants, and many other common crop diseases which center in the soil. Nitrifying bacteria may cause temporary crop injury in competing with crops for soil nitrates during the decomposition of such low-nitrogen material as straw, grasses and non-leguminous green-manure crops.

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[10] See page 361 for discussion of nitrification.

[11] See page 370 for nitrogen fixation by independent bacteria, and page 346 for nitrogen fixation by legumes.

There is always the problem of producing conditions favorable to the organisms of the soil which have a beneficial effect on plant growth, and at the same time of keeping in check those which are detrimental. Important in the maintenance of an environment favoring the activity of desirable organisms, are such soil factors as sufficient organic matter, proper soil reaction, adequate aeration, sufficient but not an excess of water, a supply of soluble salts, and a favorable soil temperature. The addition of organisms may prove beneficial as in legume inoculation and as a constituent of farm manure. The addition of available forms of fertilizer nitrogen will counteract the injurious effect of nitrate reduction caused by the decomposition of low-nitrogen forms of organic matter.

In agricultural practice the control of undesirable organisms is confined largely to producing conditions favorable to the beneficial ones. In very intensive production, especially under glass, the sterilization of the soil may be justified as a means of destroying the injurious organisms. Another common practice in greenhouse soil management is to discard the soil frequently and replace it with fresh, properly composted field soil.[12]

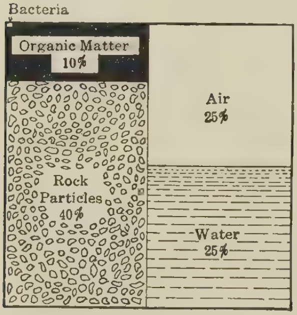

FIG. 22. MAKE-UP OF A LOAM SOIL.

The per cent by volume of constituents in a productive loam soil.

**K. A cubic foot of field soil.** A soil, to be productive, then, must contain five constituents: rock particles, organic matter, air, water, and organisms. It is of value to consider the proportion of these constituents in an average field soil that is in a good state of productivity. Figure 22 gives the approximate pro-

[12] See pages 467 and 475 for soil sterilization and compost production.

portion of the different constituents, by volume, in a productive loam.

The rock particles and water make up most of the weight of field soils. Organic matter should constitute 2 to 3 per cent of the weight of such a suface soil. The microscopic organisms are so minute that even though they occur in myriads, they constitute an infinitesimal part of the volume and weight of the soil. A cubic inch of good soil has been found to contain many millions of bacteria.

## 2. Kinds of Soils

**A. Clay, sand and loams.** A soil that contains a sufficient proportion of the small-sized particles is called a *clay soil,* or simply a *clay.* It is plastic and difficult to till. One that has a high sand content, and consequently dries out rapidly after rains, is known as *sandy soil,* or as a *sand.* In both, the name of the soil grain, clay or sand, is applied directly to the soil.

Many of our agricultural soils are classed as loams. By a *loam soil* is meant one composed of clay, silt, and sand particles mixed in such proportions that the character of the soil is not primarily dependent on any one group of soil grains. Even some gravel may occur, but never enough to make the soil gravelly in character. A soil to be classed as a loam should have insufficient clay to produce plasticity but enough clay and silt to give satisfactory moisture-holding qualities in addition to furnishing available plant-food, and should contain sand in adequate amounts for drainage and easy tillage. In short, loam is recognized as one of the most desirable soils for general agricultural purposes.

When the clay content of a soil is sufficient to dominate the silt, sand, and gravel, and the soil becomes somewhat sticky in character, though not sufficiently so to be classed as a clay, it is called a *clay loam.* Similarly, if the silt, sand, or gravel influences the character of the soil to a sufficient extent, a *silt loam, sandy loam,* or *gravelly loam* results. Although a loam is an excellent soil for most purposes, certain crops do better on clay loams, and others are best adapted to the silt loam or the sandy loam.

**B. Soil texture.** *Texture* is that property of the soil which is determined by the size of the particles that compose it. A clay soil is known as a fine-textured soil; a sandy soil is coarse textured. Fine-textured soils are frequently difficult to till. In them drainage is slow, clods and crust form easily, and they warm up slowly in the spring. Coarse-textured soils, on the contrary, are loose and friable, easy to till, drain readily, and warm up early in the spring. As a result, a soil having a heavy or fine texture is considered a *late soil,* whereas one with a light or coarse texture is considered an *early soil.* Since soil texture is dependent on the size of the soil grains, there is no practical means of modifying this property. Ordinary field manipulation of soil does not change the size of the soil grains. The only known method of materially modifying the texture of soils is through the addition of a soil of another texture. This may be practical for small flower gardens. Mixing soils of different textures is not an uncommon practice in preparing greenhouse soils, but naturally is impractical under field conditions. The clay soils of a farm will always remain heavy in texture, and the sandy soils will never change to clay.

**C. Soil structure.** *Structure* is that property of the soil which is determined by the arrangement of the soil particles. It is dependent on such factors as drainage, organic-matter content, granulation, and tillage. Two soils of exactly the same texture may differ greatly in their structural properties. A poorly drained clay soil, deficient in organic matter and improperly tilled, may be changed materially through drainage, proper tilling to facilitate granulation, and the addition of organic matter. The soil will remain a clay or clay loam, but it will be much easier to handle and far better adapted to crop production.

The practical difference, then, between soil texture and soil structure is that the texture is largely determined by natural forces during the process of soil formation, while the structure can be modified by man. The farmer may readily improve soil structure, but he must be satisfied with the texture furnished by nature. A field that is well drained and well tilled may be expected to possess good structure. Such a field is often spoken of as having good *tilth*. The structure or tilth of a soil is a reflection of the efficiency of the farmer himself.

**D. Soil surveys.** A system of classification has been worked out for field soils. It is based largely on the depth and organic-matter content of the surface soil, and the texture and color of both surface and subsoil. In addition, it takes into consideration the geological derivation, mode of formation, age, lime content, and the topography and drainage. Trained soil experts are employed by our national and state governments to make systematic examinations of soils in the field and to prepare maps indicating the location of soils of different character. This systematic study of field soils is called a *soil survey*.

Soil surveys are commonly made on the county basis. The map indicates soil variations that occur in areas 10 acres or more in extent. In addition to the soil map, a report is prepared which explains the formation of

FIG. 23. A SOIL SURVEY PARTY. (Agronomy Dept., Ill. Agr. Exp. Sta.)

A systematic study of field soils is called a soil survey.

the soils, their agricultural value, and crop adaptation; and it may offer suggestions for their practical management, including cropping, liming, and fertilizing practices. These soil surveys are a reliable and valuable source of information as to the character and value of the soils of a county. Where available, the maps and reports should be used not only by students of agriculture but also by farmers. They are of great value in connection with the selection of a farm.

**E. The soil series.** In the field classification of soils the term *series* is applied to the broad divisions. Several thousand series have been established in the United States. The soils within a series are similar in all characteristics except texture. In general, the series is made up of soils similar in geological derivation, geographic location, drainage, and organic-matter and lime content. The soil series is commonly named for a county, a town, or river in the section where it was first encountered in the soil surveys. We have, for example, the Marshall series, named for a county in Iowa; the Norfolk series, the name taken from Norfolk, Virginia; and the Mohawk, named for a river in New York State.

**F. The soil type.** The *soil type* is a subdivision of the soil series and is based on texture. The term loam, as has been explained, denotes a certain texture of soil. As long as the textural requirements are met, the soil remains a loam, irrespective of derivation or location. Obviously, there are many loam soils. When this particular grade of soil is confined to a single series, we have what is called a soil type. A type, then, is a grade of soil based on texture and confined to a single series.

The type is the real basis of soil classification. It is named by combining the name of the series with that of the soil class. For example, a loam soil occurring within the Norfolk series is called the Norfolk loam type. Other names of important soil types are Marshall silt loam, Mohawk clay loam, Houston clay, and Orangeburg sandy loam.

In the mapping of soils attention is given to the so-called *profile.* By this is meant the variations discernible to a depth of several feet. The profile is divided into *horizons,* which are designated by letters. Thus, in a given soil there may occur, beginning at the surface, the A, B, C, etc., horizons. The thickness, as well as the physical and chemical characters of these different horizons, vary in different soils. The A horizon represents the surface layer, a few inches to a foot or more in depth. It is the portion in which most of the organic matter has accumulated and corresponds closely to what has been described as surface soil. The B horizon corresponds approximately to the subsoil structure, and the C horizon to the more or less weathered rock material that might be considered in the transition state between parent rock material and soil. Though of value in soil classification and in the study of soil formation, the separation of the soil profile into horizons is little, if any, better as a basis for use in the development of systems of practical soil management than the more simple surface and subsoil division. More attention is being given to the lime content, or to the degree of acidity, of these different horizons than was done in the earlier surveys. By a comparison of the

FIG. 24. ROCK WEATHERING.

Most soils are formed by the breaking down or weathering of rocks.

horizons the relative age of different soils may be determined with a fair degree of accuracy.

**G. Residual soils.** Soils have also been classified on the basis of their formation. Such classifications are at best general in character, but are indeed interesting in that they furnish information relative to the manner in which agricultural soils have been formed.

Most soils are formed by the breaking down or weathering of rocks. Where the material remains unmoved during the weathering process so that the resulting soil occupies the same location as the original rock, the process is spoken of as rock weathering in place, or *in situ;* and the soil formed is called a *residual soil.* Such soils may resemble the parent rock, and generally are underlain by this same rock formation in an unweathered state. With residual soils there is generally a gradation from true soil through partly weathered material to the hard rock beneath, but the finely decomposed soil may rest directly on the bed rock. The breaking down of rock is due to the action of both chemical and physical forces. The process is constantly going on, and rocks are changing into soils today in the same way as they have in past ages.

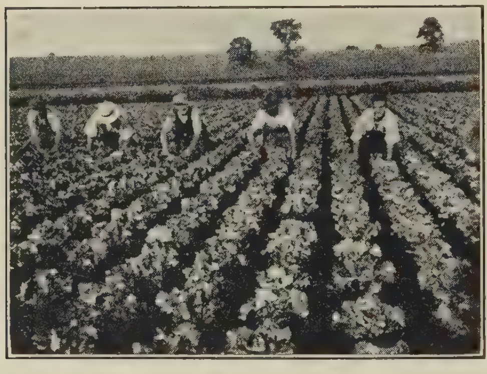

Fig. 25. Lettuce Growing on Muck. (Agronomy Dept., N. Y. State Col. of Agr.)

These swamp soils, composed largely of organic matter, are known as cumulose soils.

There are some soils that are composed almost entirely of partly decomposed vegetable matter. They occupy low areas which were at one time swamps and are often still undrained. The soil is composed largely of the accumulation from vegetative growth. These organic soils are termed *peat* or *muck*. Correctly speaking, *muck* refers to decomposed organic deposits; whereas *peat* is used to designate material that has not decomposed to such an extent that the stem and leaf structures of the original plants are destroyed. The material is also termed muck if it contains any perceptible amount of clay, silt, or sand. These swamp soils, composed largely of organic matter, are known as *cumulose soils*. Agriculturally, they are utilized for the production of hay, and when drained, for vegetable crops, particularly celery, lettuce, and onions, and also for corn and certain other field crops.

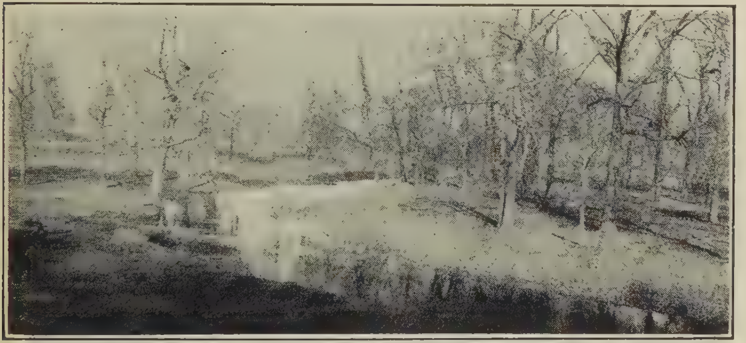

FIG. 26. BOTTOMLAND ALONG STREAM.

The bottomland along streams is termed alluvial soil.

**H. Water-deposited soils.** In many instances soil material has been transported, more or less assorted, and laid down by water. The bottomland along streams has been covered with this transported soil material. The soil in such areas is termed alluvial. It is composed largely of surface soil which has been washed from the upland, and for that reason is generally very fertile. Its agricultural value may be impaired because of insufficient drainage or lack of adequate protection from inundation.

Bordering the Atlantic Ocean and the Gulf of Mexico is a wide stretch of territory known as the Coastal Plain, which at one time was submerged. The present soils represent the material deposited by the ocean during the period when it covered this Coastal Plain section. These deposits, representing water sediments, are called *sedimentary soils.* Similar soil deposits, accumulated in lake beds and later elevated above the water level, are termed *lacustrine soils.*

**I. Ice-deposited and wind-deposited soils.** At one time much of the northern section of the United States was covered by glaciers which extended south from Canada. As these glaciers pushed down, they carried with them large quantities of debris which were deposited as the ice melted and the glaciers retreated back to the Arctic region. The present surface soils of the area covered by this ice sheet have been derived largely from this glacial material called *till,* and the soils themselves are known as *glacial soils.*

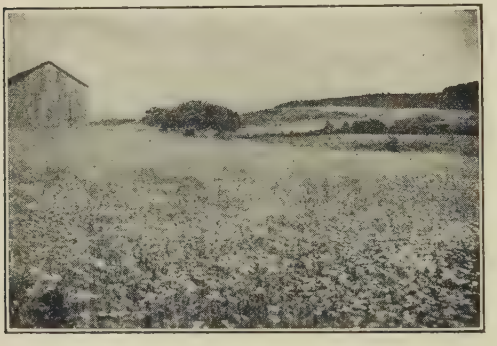

FIG. 27. GLACIAL TOPOGRAPHY.

Soils derived from glacial till are known as glacial soils.

Wind, like moving water and ice, has played its part in soil formation. In some sections of the country barren sandhills, or dunes, are being moved slowly by wind. Even some farmed land is subject to what is known as wind erosion. The dust and sand storms so common in certain sections indicate the great transporting power of the wind.

Following the glacial period, vast areas were left bare of vegetation and the surface material exposed to wind action.

Deep deposits of wind-laid material are found in certain areas, particularly in the glaciated sections of the country. Soils derived from wind-blown volcanic ash are common in some of the far western states. Such wind-blown deposits are broadly termed *aeolian soils*. The fine wind-deposited material of the glacial section of the Mississippi Valley is known as *loess* and has influenced large areas of soils in the Corn Belt.[13]

## 3. Chemical Essentials

**A. Chemistry and soil fertility.** The development of fertilizer practices, including the efficient purchase of commercial fertilizers, necessitates some knowledge of the fundamentals of agricultural chemistry. Even though few can hope to master the science of chemistry, all can, with no great difficulty, learn enough about this science in its relation to soils and crops to understand the practical application of chemistry to farming. Without an understanding of certain chemical facts, the farmer can only hope to follow blindly the fertility practices advocated by others. The following is a brief, elementary presentation of the fundamental chemical facts necessary for the understanding of the essential details of practical soil management.

*Chemistry* is the science that deals with the constitution of matter. All material things are undergoing constant change which is reflected in their chemical make-up. Chemistry is concerned with these changes and attempts to explain their causes and results. *Agricultural chemistry*, then, would include the chemical make-up of all materials essential to the successful production of farm products, the composition of the products themselves, and the chemical changes which are a necessary part of crop and animal production. It is with this practical application of chemistry to the farm that farmers are most vitally concerned.

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[13] For a more technical discussion of soil formation and classification, see Yearbook of U. S. Dept. of Agr. for 1938.

**B. Elements.** An *element* has been defined as "a substance which has definite properties and which, under ordinary conditions, is not subject to further simplification." It is a compound of molecules which are themselves made up of atoms.

All matter is made up of chemical elements, of which more than ninety have been recognized and named. Only a few are of vital importance to the farmer.

Some of the more common elements are nitrogen, phosphorus, hydrogen, oxygen, and carbon. Nitrogen is a gas. It constitutes nearly four-fifths of the atmosphere. Phosphorus in the elemental form is a wax-like substance which burns spontaneously when exposed to the air. Potassium is a solid which produces violent burning upon coming in contact with water. These three elements are purchased in fertilizers. One can readily appreciate a farmer's predicament if he should attempt to secure and apply them in their elemental form.

**C. Compounds.** Chemical elements rarely occur separately in nature except in the atmosphere, but are combined to form what are known as *chemical compounds*. Compounds, then, are chemically combined elements and as such constitute matter. Although certain of these elements are of tremendous importance to the farmer, he deals with them largely as compounds.

Nitrogen is an important fertilizer constituent. When it is combined with hydrogen in the proportion of 14 to 3 by weight, the compound ammonia is formed. Prior to about 1930 it was customary to speak of the nitrogen content of fertilizer in terms of ammonia. This compound ammonia, like the element nitrogen, is a gas and cannot be used directly as a fertilizer. A more complex compound, such as sulfate of ammonia, must be used to furnish the nitrogen of fertilizers. This compound contains, in addition to the hydrogen and nitrogen, two other elements, sulfur and oxygen. Sulfate of ammonia is a stable, soluble salt which, as purchased by the farmer, contains about 20½ per cent of nitrogen, equivalent to 25 per cent ammonia.

**D. Molecule and atom.** The *molecule* may be defined as the smallest unit of matter that normally exists alone. It is composed of *atoms*, which were at one time considered indivisible. Though known to consist of electrically charged portions called *electrons* and *protons*, atoms normally react as units in the chemical changes with which agriculture is concerned.

Although the atom is invisible, it is known to vary in weight in the different elements. The comparative weights of the atoms of the various elements have been determined and are expressed on the basis of 1 for the weight of normal hydrogen. An atom of oxygen weighs 16 times as much as an atom of normal hydrogen and, therefore, has a so-called *atomic weight* of 16. The atomic weight of nitrogen is 14, of phosphorus 31, of potassium 39, and of carbon 12.

**E. Symbols.** *Chemical symbols* are abbreviations used to designate elements. They might be called the nicknames of the elements. For many of the agriculturally important elements, the first letter of the name is used as the symbol. For example, N is the symbol for nitrogen, P for phosphorus, H for hydrogen, and O for oxygen. In other instances, an additional letter is used in the symbol, as Ca for calcium, an important constituent of lime. The symbol K, used for potassium, comes from *kalium*, which is the Latin word for the potassium compound, potash.

**F. Formulas.** The *formula* is the abbreviated expression of the composition of a chemical compound. It consists of a combination of the symbols of the elements entering into a compound. It also expresses the number of atoms of these elements which are combined to form a molecule of a compound.

The compound ammonia, as already explained, consists of nitrogen and hydrogen. These elements have been combined in the proportion of 1 atom of nitrogen to 3 atoms of hydrogen. The formula for this compound is $NH_3$; the letters refer to nitrogen and hydrogen, respectively, and the figure 3 designates the number of hydrogen atoms. In the same way, the formula $P_2O_5$ designates a compound of the elements phos-

TABLE I

Chemical Elements and Radicals with Symbols, Atomic Weights, and Valences

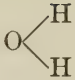
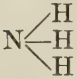
| Elements | Character of Electrons | Symbol | Atomic Weight | Valence |
|---|---|---|---|---|
| Aluminum | + | Al | 27 | 3 |
| Boron | ....... | B | 10.8 | 3 |
| Calcium | + | Ca | 40 | 2 |
| Carbon | ....... | C | 12 | 4 |
| Chlorine | − | Cl | 35.5 | 1 |
| Copper | + | Cu | 63.5 | 1–2 |
| Hydrogen | + | H | 1 | 1 |
| Iodine | − | I | 126.9 | 1 |
| Iron | + | Fe | 56 | 2–3 |
| Magnesium | + | Mg | 24 | 2 |
| Manganese | + | Mn | 55 | 2–3–4–6–7 |
| Nitrogen | ....... | N | 14 | 3–5 |
| Oxygen | − | O | 16 | 2 |
| Phosphorus | ....... | P | 31 | 3–5 |
| Potassium | + | K | 39 | 1 |
| Silicon | ....... | Si | 28 | 4 |
| Sodium | + | Na | 23 | 1 |
| Sulfur | − | S | 32 | 2–4–6 |
| Zinc | + | Zn | 65.3 | 2 |
| RADICALS | | | | |
| Carbonate | − | $CO_3$ | 60* | 2 |
| Hydroxide | − | OH | 17* | 1 |
| Nitrate | − | $NO_3$ | 62* | 1 |
| Phosphate | − | $PO_4$ | 95* | 3 |
| Sulfate | − | $SO_4$ | 96* | 2 |

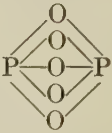
* Weight of combined atoms.

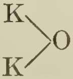
phorus and oxygen in which the atoms are combined in the proportion of 2 of the former to 5 of the latter. This compound is known agriculturally as phosphoric acid, and is still commonly used to express the phosphorus content of fertilizers. The formula for potash is $K_2O$. The potassium content of fertilizers is expressed as the compound potash.

**G. Chemical change.** When elements combine to form a compound, a rearrangement of the atoms and molecules takes place. This is a *chemical change* or *chemical reaction.* Compounds may unite or break apart to form new compounds. This represents a very common type of chemical change. Any alteration whatever in the molecular make-up of matter constitutes a chemical change, and is always accompanied by a gain or loss in energy.

In the chemical change of matter, atoms of the different elements vary in the number of atoms of another element which they will hold or replace. For example, hydrochloric acid ($HCl$) consists of 1 atom of hydrogen combined with 1 atom of chlorine. In water ($H_2O$) we find that 2 atoms of hydrogen are combined with 1 atom of oxygen, and in ammonia ($NH_3$) there are 3 atoms of hydrogen to 1 of nitrogen. The term *valence* refers to the number of atoms of hydrogen or chlorine which may be held or replaced by an atom of a specified element. Hydrogen and chlorine have a valence of 1 each; oxygen, then, based on the composition of water, would have a valence of 2. Nitrogen combines with 3 atoms of hydrogen to form ammonia, and is said to have a valence of 3. Some elements have other valences, and a few have more than 1 valence each.

The structural formula of a chemical compound showing the valence relationships of the elements composing it may be made clear by the use of simple diagrams. For example, the relationship of the hydrogen and chlorine in hydrochloric acid could be shown thus: $H—Cl$, with the symbols of the two elements joined by a single line which would indicate that each had a valence of 1, or that each was monovalent. The formula for water could be graphically represented as , which would indicate a valence of 2 for oxygen, and the formula for ammonia as , showing a valence of 3 for nitrogen.

Phosphoric acid, as the term is used agriculturally, refers to the compound $P_2O_5$, in which phosphorus has a valence of 5 and oxygen of 2. The structural formula would be , which shows 5 valences for each phosphorus atom and 2 for each atom of oxygen.

Potassium oxide, commonly referred to as potash, would have the structural formula  since the two monovalent potassium elements are combined with one divalent oxygen element.

Valence is dependent on the number of positive or negative electrons which an atom of an element possesses. These electrons may be exchanged or shared in pairs by two atoms. However, in a compound there are an equal number of positive and negative valences.

In Table I the valences are recorded, as well as the symbols and atomic weights of the more important elements with which one is concerned in the study of soil and the growth of plants. The metals carry a positive charge and are marked " + "; the non-metals carry a negative charge and are designated as " − ". The radicals—combinations of elements which in forming other compounds function similarly to individual elements—are also listed.

**H. Molecular weights.** When elements combine chemically to form compounds, they always unite in a definite proportion by weight. The *molecular weight* is the sum of the weight of the atoms constituting a molecule of a compound. The weight of an atom of hydrogen is 1, for convenience, say, 1 pound. That of oxygen is 16. Two atoms of hydrogen weighing 1 pound each would combine with one 16-pound atom of oxygen to form 18 pounds of water. Eighteen pounds of water, then, consists of 2 pounds of hydrogen and 16 pounds of oxygen. By weight, water is $^2/_{18}$, or $^1/_9$, hydrogen, and $^{16}/_{18}$, or $^8/_9$, oxygen. The molecular weight of water is 18.

Phosphorus, with an atomic weight of 31, combines with oxygen (atomic weight 16) to form phosphoric acid, $P_2O_5$. In this compound the elements occur in the proportion of 62 pounds of phosphorus (2 × 31) to 80 pounds of oxygen (5 × 16). Therefore, 142 pounds of phosphoric acid contains 62 pounds of phosphorus and 80 pounds of oxygen. One ton contains 873 pounds ($^{62}/_{142} \times 2000$) of phosphorus and 1127 pounds ($^{80}/_{142} \times 2000$) of oxygen.

In the study of fertilizers it is important to appreciate clearly this relation of the molecular weight to the composition of compounds. Too few farmers understand the relationship between the phosphorus and phosphoric acid in their fertilizers, or the relative composition of burned lime and ground limestone.

The chemical compounds of greatest importance in the study of soils and fertilizers are listed, together with their formulas and molecular weights, in Table II.

**I. Acids, bases, and salts.** An *acid* is a chemical compound containing replaceable hydrogen. A *base* or *alkali* is a chemical compound capable of uniting with the replaceable hydrogen of an acid, thereby neutralizing the acid and forming a salt. Certain of the chemical elements combine with hydrogen, or hydrogen and oxygen, to form acids; others unite with hydrogen and oxygen to form bases. Chlorine in combination with hydrogen forms hydrochloric acid, HCl. Sulfur combines with hydrogen and oxygen to form sulfuric acid, $H_2SO_4$. Calcium, on the other hand, when combined with hydrogen

TABLE II

Chemical Compounds with Formulas and Molecular Weights

| Name | Formula | Molecular Weight |
|---|---|---|
| Aluminum sulfate | $Al_2(SO_4)_3$ | 262 |
| Aluminum silicate | $Al_2Si_2O_7$ | 222 |
| Ammonia | $NH_3$ | 17 |
| Ammonium hydroxide | $NH_4OH$ | 35 |
| Ammonium sulfate | $(NH_4)_2SO_4$ | 132 |
| Calcium carbonate | $CaCO_3$ | 100 |
| Calcium hydroxide | $Ca(OH)_2$ | 74 |
| Calcium oxide | $CaO$ | 56 |
| Calcium sulfate | $CaSO_4$ | 136 |
| Carbon dioxide | $CO_2$ | 44 |
| Hydrochloric acid | $HCl$ | 36.5 |
| Magnesium carbonate | $MgCO_3$ | 84 |
| Magnesium hydroxide | $Mg(OH)_2$ | 58 |
| Magnesium oxide | $MgO$ | 40 |
| Nitric acid | $HNO_3$ | 63 |
| Phosphoric acid | $H_3PO_4$ | 98 |
| Phosphoric acid (agriculturally) | $P_2O_5$ | 142 |
| Monocalcium phosphate | $CaH_4(PO_4)_2$ | 234 |
| Dicalcium phosphate | $Ca_2H_2(PO_4)_2$ | 272 |
| Tricalcium phosphate | $Ca_3(PO_4)_2$ | 310 |
| Potassium chloride | $KCl$ | 74.5 |
| Potassium sulfate | $K_2SO_4$ | 174 |
| Sodium chloride | $NaCl$ | 58.5 |
| Sodium nitrate | $NaNO_3$ | 85 |
| Water | $H_2O$ | 18 |

and oxygen forms hydrated lime, $Ca(OH)_2$, used for correcting the acidity of soils.

A *salt* is a chemical compound resulting from a chemical reaction between an acid and an alkali. A neutral salt is neither acid nor alkaline in character. Common table salt will result from mixing the proper amounts of sodium hydroxide, NaOH, a caustic alkali similar to lye, and concentrated hydrochloric acid, HCl. Both the hydroxide and the acid are poisons; but when they are mixed in the proper proportion, a chemical change takes place and two harmless compounds, water and common salt, result.

**J. Ions and ionization.** Many compounds, when dissolved, partially separate into electrically charged portions called *ions*. These ions may consist of single atoms or groups of atoms, some carrying a positive charge and others a negative charge of electricity. The breaking up of a compound into ions is called *ionization*.

Acids, bases, and salts usually undergo ionization to some extent, at least when they enter into solution. With an acid, such as hydrochloric (HCl), the molecules split into positive or $+H$ ions, called *anions*, and negative or $-Cl$ ions, called *cations*. The strength of an acid solution is dependent on the ionized hydrogen which it contains. The acidity of the soil is frequently expressed in terms of hydrogen-ion concentration of the soil solution.[14]

**K. Base exchange.** The colloidal content of the soil is often referred to as the *colloidal complex*. Until relatively recent years, its significance in various chemical, physical, and biological activities within the soil was not appreciated. Even today these activities in their relation to plant growth are not fully understood. They constitute an interesting field of study for the research chemist.

It has been found that the colloidal material, though too fine for the individual particles to be identified by microscopic examination, is made up of crystals which consist of thin layers or plates. Water may move in or out from between these plates resulting in expansion or contraction. Thus, soil expands on becoming wet and contracts on drying, and the greater the content of colloidal material the greater the degree of expansion and contraction.

The colloids are composed largely of aluminum and iron silicates. Between the layers or plates of silicates are cations of such elements as calcium, magnesium, potassium, hydrogen, and sodium. These are subject to replacement by other positively charged ions. Such replacement or exchange of ions is called *base exchange.*

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[14] See General Information, Chapter VI, for relation of hydrogen-ion concentration to the liming of soils.

From the standpoint of supplying nutrients to plants, this property of the colloidal complex of the soil is of practical importance, for it enables the soil to hold in a form usable by plants such nutrients as ammonia, calcium, magnesium, and potassium. It is largely as the result of base exchange that the water-soluble potash content of fertilizers and the nitrogen content also, when such nitrogen is in the form of ammonia, are not subject to serious leaching from the soil.

**L. Essential elements.** At one time it was thought that only 10 chemical elements were absolutely essential for plant growth. The 10 formerly called *essential elements* and now referred to as *major nutrient* or *fertilizer elements,* are:

1. Nitrogen.
2. Phosphorus.
3. Potassium.
4. Sulfur.
5. Calcium.
6. Magnesium.
7. Iron.
8. Carbon.
9. Hydrogen.
10. Oxygen.

Recent investigations have shown that other elements are essential in minute quantities, and that the growth of crops on certain soils is benefited by their application. They are commonly spoken of as *minor* or *rarer nutrient* or *fertilizer elements.* Additional knowledge will undoubtedly modify any attempted listing. The following group of so-called minor nutrient elements is based on the most reliable information available.

1. Boron.
2. Chlorine.
3. Copper.
4. Iodine.
5. Manganese.
6. Silicon.
7. Sodium.
8. Zinc.

Of these, boron, manganese, copper, and zinc are of especial importance. Although they are required in small amounts, larger quantities of these elements, especially boron, may become very toxic to plants.

Of the nutritive elements, carbon, hydrogen, and oxygen are secured mostly from air and water. The nitrogen supply is furnished largely by the soil organic matter, but atmospheric nitrogen is utilized by leguminous plants. The other elements are supplied both by the mineral and organic-soil material.

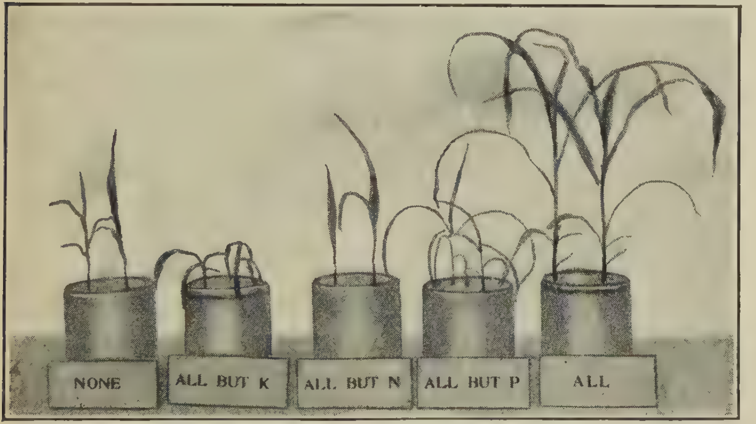

Fig. 28. Corn Growing in Sand. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Of the essential elements of growth, nitrogen, phosphorus, and potassium are considered the real fertilizer elements.

Nitrogen, phosphorus, and potassium supply most of the nutritive value of commercial fertilizers and may be considered the three real or major fertilizer elements. However, certain of the other elements listed, especially calcium, chlorine, magnesium, and sulfur, are contained in most mixed fertilizers, and all are present in small amounts, at least, in farm manure. All agricultural lime contains calcium, and often magnesium as well. Consequently, in liming soils to reduce acidity these two elements are generally supplied. Calcium, magnesium, sulfur, iron, boron, manganese, copper, and zinc constitute the group of minor fertilizer elements.

The eighteen elements mentioned are listed with their symbols, valences, and atomic weights in Table I. In Table II are grouped most of the important compounds which enter into practical problems of soil fertilization and crop production. One should be thoroughly familiar with this tabulated material, as it is essential to the further study of soil fertility.[15]

It has been found that substances called *plant hormones* may at times have a stimulating effect on the growth of seedling plants. Little is known about such substances, and their practical value appears to be confined to the stimulation of root growth in young plants which are being transplanted. Their importance for the treatment of soils has probably been overrated in order to stimulate sales. So far as is known at present, they cannot be used to any advantage in the production of field crops.

### 4. PLANT-FOOD SUPPLY

**A. Soil analysis.** The productivity of a soil is largely dependent on the supply of plant-food that becomes available during the cropping season. The three elements nitrogen, phosphorus, and potassium are most likely to be deficient in farmed soils. Calcium and magnesium are frequently deficient, at least in available form. A deficiency of active calcium is generally associated with high soil acidity. The other elements are rarely inadequate for the normal growth of crops. It is of importance to know something about the plant-food supply of the soil and its relation to fertilizer practices.

The chemist can analyze a sample of soil and determine the amounts of the various chemical elements which it contains. Because many factors other than soil composition must be considered in determining the system of fertilization, the results of a chemical analysis are not sufficient to enable either the chemist or the farmer to determine just what fertilizer will be most profitable in a given year. Even so, the plant-food content of the soil, as revealed by chemical analysis, is of importance. This information has been helpful in the development of modern systems of soil fertilization. Further chemical studies of field soils may be expected to reveal additional information necessary for the development of more efficient systems of soil management.[16]

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[15] Unless students have had a course in chemistry, this discussion should be supplemented with a few simple laboratory demonstrations, such as outlined in "The Chemistry of Farm Practice," by T. E. Keitt, published by John Wiley & Sons.

**B. Available plant-food.** The plant-food of the soil is supplied partly by the rock material or mineral matter, and partly by the organic matter. Under either condition the chemical elements occur as compounds. These compounds are relatively stable in character and are insoluble in water. The plant-food is said to be in an unavailable form. Before plants can utilize it, chemical change must take place and new compounds which are soluble in the water of the soil must be formed. As organic matter decomposes in the soil, the carbon liberated may unite with oxygen, forming carbon dioxide. This unites with water to produce carbonic acid, $H_2CO_3$, which functions in making the plant-food available. Productivity depends not primarily on the total amount of plant-food in a soil, but rather on the amount which becomes available during the cropping season. It is also dependent to some extent on the proper balance or proportional amounts of the soluble forms of these elements. Other things being equal, the amount of plant-food becoming available is in proportion to the total supply. However, certain methods of soil treatment and manipulation increase the rate at which the unavailable plant-food changes to the available form. In general, it can be said that good farming makes plant-food available; poor farming keeps it locked up in the soil.

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[16] See General Information at end of Chapter VII for discussion of simplified soil tests.

**C. Weight of plowed soil.** The chemical composition of a soil is commonly expressed in terms of pounds of plant-food to the acre. The amounts of nitrogen and phosphorus are generally so small that they constitute only a small fraction of a per cent of the weight of the soil. It is of interest in this connection to know something about the weight of field soils. The plowed soil of an acre has been found to weigh, when thoroughly dry, about 2,000,000 pounds. Peat and muck have been estimated on the same basis as having a weight of 1,000,000 pounds. These figures are based on the assumption that soils are, on the average, plowed to a depth of approximately 7 inches. Subsoils are similar in weight, and may be estimated on the basis of 2,000,000 pounds an acre for each 6-inch depth of mineral soil, and 1,000,000 for peat and muck.

**D. Potassium, phosphorus, and sulfur.** The potassium, phosphorus, and sulfur content of the soil occurs largely in the mineral material, though soil organic matter contains a small amount of potassium and phosphorus and as much as one-half of the sulfur. The common soil-forming rocks contain relatively large amounts of potassium, so that the soil grains resulting from their disintegration are well supplied with this constituent. Some mineral soils have been found to be deficient in total potash. Particularly is this true of sandy soil which generally has a high quartz content. Whereas such soil may contain less than 10,000 pounds of potassium in the surface 7 inches of an acre, most farm soils have from 20,000 to 40,000 pounds of potassium to the acre. The availability, rather than the total amount of potassium, is of most concern to the farmer.

Soils are not so well supplied with phosphorus and sulfur. The latter element is constantly being supplied by rain and by commercial fertilizers. In some instances, especially in the northwestern states, soils have been found deficient in sulfur for some crops—alfalfa in particular. Phosphorus is a universal constituent of mixed fertilizers, and, so far as is known, must be supplied to most soils in some commercial form to maintain crop yields. Superphosphate is a fertilizer extensively used to supply phosphorus. Farmed soils may be expected to contain between 500 and 1500 pounds of sulfur and of phosphorus to the acre 7 inches.

**E. Calcium and magnesium.** While the two mineral elements, calcium and magnesium, are required for the nutrition of plants, they are of greatest practical value because of their relation to soil acidity. They are not commonly so deficient in the soil that crops suffer on account of an inadequate amount of either one as plant-food. However, an inadequate supply in the form of certain chemical compounds permits the soil to become too acid for many crops, and the injurious effect of acidity may be due to insufficient quantities, especially of calcium in an available form. In the form of agricultural lime, calcium and magnesium are added to the soil for the purpose of counteracting the acidity, or, as is sometimes said, to sweeten the soil. Magnesium sulfate is applied to some extent when soils have been found to have a magnesium deficiency.

Surface soils to the plow depth may be expected to contain, to the acre, from 5000 to 10,000 pounds or more both of calcium and of magnesium. The amount depends partly at least on the lime content of the parent rock. In a soil derived from limestone, a high calcium and usually a high magnesium content may be expected. In dry climates the calcium and magnesium content of soils may be especially high because the rainfall has been insufficient to remove these elements through leaching.

**F. Nitrogen and organic matter.** The nitrogen of soils is found largely in the organic matter. As this organic matter decomposes, the nitrogen becomes available and is either used by plants or leached from the soil. In arid sections soluble nitrogenous salts may accumulate in the soil because there is insufficient rain to wash them out or to permit any great amount of plant growth. If, through careless systems of management, the organic-matter content of a soil is permitted to become depleted seriously, the injurious effect on most crops is due primarily to an inadequate supply of available nitrogen. In fact, there is such a close relationship between the supply of active organic matter and the nitrogen content of farmed soils that a marked deficiency of one constituent indicates a lack of the other.

It is not an easy matter to maintain the organic-matter supply at a high level. Fresh organic matter is constantly subject to decomposition, and the supply can never be greatly increased when a soil is cropped. Humus accumulation is dependent on the supply of nitrogen since the nitrogen-carbon ratio seldom exceeds 20 to 1. Therefore, the return to the soil of organic matter with a high nitrogen content is necessary for the rapid accumulation of humus. Consequently, farm manure and legume green manure crops are more efficient sources of organic matter than are straw and non-legume green manures.

Since the effectiveness of organic matter in supplying nutrients is dependent to a large extent on the rate of decomposition, it is of importance to appreciate the factors which influence this important biochemical process. Immature green plants will decompose more rapidly than mature ones. An adequate supply of nitrogen to satisfy the needs of the decomposing bacteria is essential. For this reason the addition of fertilizer nitrogen, especially to material with a low nitrogen content, will hasten the process. Otherwise, soil conditions must be made favorable for the activity of the nitrifying bacteria of the soil. Adequate soil aeration is important, as is a favorable soil reaction. Consequently, adequate drainage and tillage should be provided and sufficient lime applied to counteract soil acidity to the point favorable to the functioning of the decomposing organisms.

Since most soils are not abundantly supplied with organic matter, they have a relatively low nitrogen content. This nitrogen is confined largely to the surface soil. Only in arid regions is there any great amount of nitrogen in subsoils. This means that the crop-producing capacity of a soil will be exhausted as the organic matter in the surface layer completely decomposes into humus and its supply of nitrogen is largely liberated. This element can be supplied as fertilizer, but it is expensive and, at best, can be used in relatively small amounts except in intensive systems of farming. For most field crops, it has been found necessary to supplement the soil supply of nitrogen through the application of manure and the production of legumes.

Surface soils generally contain from 1000 to 5000 pounds of nitrogen to the acre 7 inches. Some sandy soils, particularly in the South where climatic conditions have been especially favorable for the decomposition of organic matter, may contain less. The brown and black prairie soils may have as much as 10,000 pounds, and some peat has 40,000 pounds of nitrogen to the acre.

**G. Alkali soils.** Alkali soils differ greatly from ordinary soils in composition. Their one outstanding characteristic is their high soluble-salt content, but in addition they are generally poorly supplied with organic matter. They are unproductive, not because of a deficiency of plant-food, but rather because of an overabundance of soluble salts. In the management of alkali soils, one is concerned with the reduction of the soluble-salt content of the soil, and not with the application of additional soluble material in the form of commercial fertilizers.

**H. Composition of farm soils.** Although neither the immediate productiveness nor the fertilizer requirement is entirely dependent on the soil composition, it should be evident that chemical soil analysis has furnished information of tremendous value. In order properly to interpret the results of an analysis of a soil, which gives the total plant-food content, a standard for comparison is necessary. The composition of a soil capable of furnishing adequate amounts of nitrogen, phosphoric acid, and potash for maximum crop growth would furnish such a standard. A soil containing the following total amounts of plant-food in the surface 7 inches of an acre would be expected to meet this requirement:

| | |
|---|---|
| Nitrogen (N) .................. | 5,000 pounds |
| Phosphoric acid ($P_2O_5$) ......... | 4,500 pounds |
| Potash ($K_2O$) .................. | 10,000 pounds |

Not only should these plant-food constituents be present in proper amounts, but in addition there should be no marked lime deficiency, or the resulting soil acidity would seriously interfere with the production of certain of the common field and garden crops. The composition of several representative soils is given in Table III.

It is of importance to remember that the plant-food in the soil must be in an available form—that is, dissolved in the soil solution—before plants can utilize it. Consequently, it is a question not only of the total soil supply of plant-food, but also of the rate at which this supply becomes available. Nor should one overlook the fact that good systems of farming not only return plant-food to the soil, but likewise maintain a high rate of availability of that supplied by the soil.

In addition to analyzing soils for their total plant-food content, determinations of the so-called available supply have been made. Weak acid solutions of such concentration that theoretically they would dissolve only the soil nutrients available for the growth of plants were first used, but with no great degree of success. Comparatively recently there have been developed more or less simplified tests commonly referred to as *rapid* or *quick soil tests* for determining nutrient deficiencies of soils. The results may often be of value if the tests are made by an experienced laboratory technician, and interpreted by someone with wide experience in evaluating the various factors influencing the growth of crops. However, in themselves, the results of such tests can never be used successfully for determining the best system of fertilizing a particular soil or an individual crop. In fact, no known method of soil chemical analysis supplies this information.

Chemical soil studies have been and still are being used in solving the many intricate problems associated with the fertility of the soil and the growth of plants. Information secured as the result of any reliable method of chemical soil analysis, whether it determines total or available plant-food, may be of value as supplemental information in developing practical systems of soil management, including fertilizer practices. However, one should never make the mistake of basing the fertilizing or liming practice solely on the result of soil tests.

TABLE III

COMPOSITION OF SURFACE SOILS

| Description of Soil | Location | Pounds of Total Plant-Food in 2,000,000 Pounds of Soil | | | |
|---|---|---|---|---|---|
| | | Nitrogen N | Phosphoric acid ($P_2O_5$) | Potash ($K_2O$) | Lime (CaO) |
| Limestone valley | Pennsylvania | 2,400 | 2,300 | 69,600 | ....... |
| Residual (shale) | West Virginia | 2,750 | 1,624 | 26,400 | ....... |
| Glacial (limestone) | New York | 4,800 | 3,220 | 40,440 | 2,520 |
| Glacial (shale) | New York | 5,200 | 2,732 | 44,616 | 259 |
| Coastal plain | New Jersey | 1,300 | 3,119 | 18,836 | 2,560 |
| Maryland barrens | Maryland | ........ | 414 | 2,400 | 812 |
| Piedmont plateau | No. Carolina | 790 | 1,288 | 55,440 | 4,452 |
| Coastal plain sand | So. Carolina | 759 | 867 | 11,992 | ....... |
| Timbered glacial soil | Ohio | 1,860 | 2,116 | 4,756 | 5,180 |
| Gray prairie | Illinois | 2,777 | 1,868 | 30,798 | 5,820 |
| Brown prairie average | Iowa | 5,458 | 3,209 | 34,490 | ....... |
| Peat (1,000,000 lbs.) | Wisconsin | 33,900 | 3,611 | 5,820 | ....... |
| Upland, Brazos Co. | Texas | 1,620 | 695 | 15,518 | 6,201 |
| Gray timber soil | Missouri | 2,800 | 2,530 | 41,821 | 18,400 |
| Prairie | Kansas | 2,800 | 1,686 | 19,716 | 10,800 |
| Residual limestone | Kentucky | ........ | 1,895 | 32,063 | 11,918 |
| Black prairie (glacial) | No. Dakota | 6,335 | 3,050 | 31,100 | ....... |

## COMMUNITY STUDIES

1. If a soil survey has been made of the local county, secure a copy of the soil map and report and use them in connection with your field studies of the soil.

2. Determine, if possible, the geological formation of the soil of your community. If more than one formation exists, compare the soils of the different formations. Road and railroad cuts afford good opportunities for studying the character of soil formations.

3. With a soil auger or spade, excavate the soil to a depth of 2 or 3 feet. Determine the depth and color of the surface soil. The color of the subsoil.

4. Examine the surface soil carefully. Is it sandy or sticky in character? Would you class it as loam, sandy loam, silt loam, clay loam, or clay? What is the texture of the subsoil?

5. Compare the organic-matter content of the surface soil and subsoil. Is this soil well supplied with organic matter?

6. If the soils have been surveyed, compare several of the different types, and locate on the land the boundary lines between them as shown on the soil map.

7. Examine the surface soil of an old field, and of virgin timber land. What differences do you find?

8. Are the soils of the community equally well drained? If not, what causes the difference? Are any of the farm soils artificially drained?

9. Are there any abandoned farms in your community? If so, list the main reasons why these farms are submarginal.

10. Does the natural vegetation in your community indicate good or poor soils? Does it indicate an acid soil condition? What do the farm crops indicate as to fertility and acidity conditions?

11. List the advantages and disadvantages of your home community for the types of farming followed.

## PROBLEMS

1. How many pounds of chlorine are there in 36.5 pounds of hydrochloric acid?

2. State the chemical formula for calcium oxide, and calculate the percentage of calcium and of oxygen in this compound. See Table II.

3. What would be the percentage of phosphoric acid in the surface of a mineral soil which contains 3000 pounds of this plant-food in the plowed soil of an acre? Of a peat or muck soil that contains 1500 pounds of phosphoric acid?

4. List the names of the elements and of the compounds that enter into the following chemical reactions: $CaCO_3 + 2HCl = CaCl_2 + CO_2 + H_2O$? Which is a base, which an acid, and which a salt?

## REFERENCES*

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Types of Farming and Farm Business Studies. S. C. Bul. 310.
Types of Farming in Tennessee. Tenn. Bul. 170.

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* Only publications available for distribution are listed. There are numerous experiment station bulletins and circulars dealing with soil problems that are out of print, but which may be found in agricultural libraries. To obtain copies of current lists of publications consult the United States Dept. of Agr. and the experiment stations. The addresses of the agricultural experiment stations are given in the Appendix. For reference books on management and fertilization of soils see Appendix.

# CHAPTER II

## GROWING THE CROP

The soil is by no means the only factor to which one must look in the production of farm crops. Their successful production necessitates an understanding of how plants grow and of their requirements for good yields. Therefore, the essentials of plant growth must be understood in order that the soil may be managed in such a way as to meet adequately the needs of the crop.

**Operations:**

1. Supplying the crop needs.
2. Fertilizing different crops.

### 1. Supplying the Crop Needs

For the successful production of farm crops, the requirements for normal growth must be supplied in a practical way.

**Factors to be considered:**

A. Seed.
B. Seed-bed.
C. Light, air, and heat.
D. Water.
E. Nourishment.
F. Negative factors.
G. Crop rotation.

**A. Seed.** Most farm crops are reproduced by means of seed, though vegetative parts, such as cuttings and runners, are employed in growing certain fruits and vegetables. With potatoes and similar crops which are reproduced by means of tubers, it has become customary to apply the word *seed* to the tubers that are saved for planting, designating them by a term such as *seed potatoes.* Obviously, either seed, or living tissue of some sort, is absolutely essential for the growth of plants.[1]

In agricultural practice the choice of seed is a most important factor in the successful production of crops. The seed, first of all, must show a high percentage of germination. Test the seed if there is any doubt as to its germinating quality. The size of seed influences the yield. When it is practical, separate out the small and immature seed, and plant only the large ones. Clean seed is desirable. Seedsmen commonly remove the weed seed and other impurities from their product before it is marketed, nevertheless, in the purchase of seed, both purity and germination should be checked. Home-produced seed oats, wheat, and barley should be put through a fanning mill.

The ability of a plant to produce is an inherited characteristic. Seed capable of producing good yields must itself have been produced by high-yielding plants. Some varieties have been found to possess high-yielding qualities. Much has been accomplished through plant breeding and selection in the origination and improvement of strains and varieties of farm crops. Recently, as the result of double crossing, high-yielding strains of certain grain and silage crops have been developed. There is a large amount of information available today relative to the adaptation of crop varieties to the climatic and soil conditions of the various sections of the country.[2]

For the successful production of red clover and alfalfa in the northern states, hardy, northern-grown seed must be used.

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[1] See General Information at end of chapter for explanation of *seed germination.*

[2] See "Crop Production and Soil Management," by J. F. Cox, published by John Wiley & Sons, for crop varieties and the selection and testing of seed.

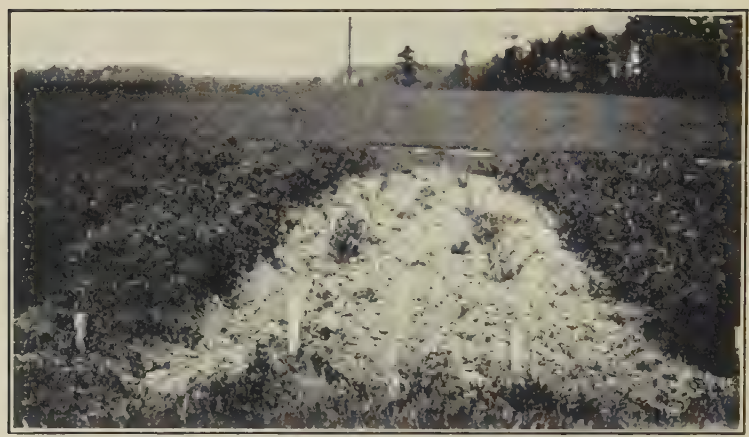

Fig. 29. Winter Killing of Alfalfa. (Agronomy Dept., N. Y. State Col. of Agr.)

For the successful production of red clover and alfalfa in the northern states, hardy, northern-grown seed must be used.

Fig. 30. A Well-Prepared Seed-Bed. (Agronomy Dept., Ill. Agr. Exp. Sta.)

A well-prepared seed-bed is essential in the production of most crops.

Certain crop diseases, such as potato scab and oat smut, are carried by the seed. Control these diseases by treating the seed.

**B. Seed-bed.** The germination of the seed and the growth of the plant are dependent on the quality of the seed-bed. A well-prepared seed-bed is essential in the production of most crops. The soil functions as a foothold or home of the plant roots, and as such may be materially modified in character by the farmer. It is commonly spoken of as supplying mechanical support for growing plants. The texture of the soil, which is determined by the size of the soil grains, cannot be changed, but the structure or tilth may be improved through proper soil manipulation and treatment. Good seed-bed preparation, which at the same time furnishes favorable conditions for the proper development of the roots of crops, is dependent largely on drainage, an adequate supply of organic matter, and proper tillage.

**C. Light, air and heat.** Light is an absolute essential for the growth of ordinary plants. The successful growing of crops requires not only light but a certain amount of actual sunshine.

Any growth made by plants in the absence of light lacks the green color so characteristic of vegetation. Everyone is familiar with the sprouting of potatoes in the dark cellar. So long as light is excluded, the sprouts are white; but when potatoes sprout in the light, green leaves are developed. This green coloring matter, called chlorophyll, the presence of which is dependent on light, is absolutely necessary for the nutrition and growth of the ordinary farm crops. Since the farmer has little or no control over light, it is fortunate that nature has made adequate provision for furnishing this essential of plant growth.

Plants draw heavily on the air for nourishment. In fact, they secure a much larger proportion of their nutrient requirements from the atmosphere than from the soil. Without air, plant growth would cease. Fortunately, as with light, nature ordinarily provides an adequate supply of air. The farmer need give no thought to the air supply in the growing of field crops except when, owing to poor drainage or poor tilth, the soil becomes inadequately aerated.

A certain amount of heat is necessary for seed germination and for plant growth. The seed of some plants will germinate at a much lower temperature than that of others. In the same way, some plants continue their growth when the temperature is low enough to retard that of other kinds of vegetation. As the freezing point is approached, both germination and growth cease. The optimum or most favorable temperature for the growth of a given crop is always considerably above that which permits growth. For example, corn will make some growth with the temperature as low as 50 degrees, but the maximum rate of growth is not obtained until the temperature rises to a little above 90 degrees.

When the soil temperature exceeds the optimum for a given crop, the rate of growth is reduced. The low carrying capacity of permanent pastures in midsummer is often due to high soil temperature as much as or more than to inadequate moisture.

Table IV gives the minimum and optimum temperatures for the growth of some of the common farm crops. Germination temperatures are about the same as those given for growth.

The sun is the great direct source of heat. The heat, which it radiates, is partly absorbed by the soil during the day, and given off to some extent at night. The rapidity with which a soil absorbs the sun's rays is partly determined by the surface color. A black soil warms up more rapidly than a gray one. Wet soils warm up slowly. This is due to the large amount of heat required to raise the temperature of water, and also to the cooling effect of its evaporation from the surface.

Except where crops are grown under glass, the producer has little control of temperature. Crops must be grown "in season" for best results. The different crops have, to a certain extent, their territorial limitations. For instance, there are the Cotton Belt, the spring-wheat section, and the citrus-fruit districts in the United States. Some crops are very much restricted in their climatic adaptation; others can be grown successfully in sections differing widely in temperature. Pineapples, cotton, and spring wheat are examples of the former; rye, clover, and alfalfa, of the latter. A short-season crop may be expected to have a wider territorial adaptation than one requiring a long season for full maturity.

### TABLE IV

### Temperature for the Growth of Crops

(Average Degrees Fahrenheit)

| Crop | Minimum | Optimum |
|---|---|---|
| Barley | 40 | 84 |
| Corn | 48 | 93 |
| Melon | 60 | 98 |
| Oats | 35 | 77 |
| Peas | 40 | 82 |
| Clover | 40 | 75 |
| Wheat | 41 | 84 |

**D. Water.** Crops require enormous amounts of water. Soil water is constantly being taken in through the root system, and given off through the leaves by transpiration. A 40-acre field of corn during the stage of maximum growth transpires fully 800 tons of water daily. Unless the soil is capable of supplying adequate amounts of water, crops cannot make their maximum growth, and correspondingly low yields result. Green plants, on an average, are made up of 25 per cent dry matter and 75 per cent water. Some contain as much as 90 per cent water. Crops require from 200 to 600 pounds or more of water for each pound of dry matter produced. Assuming that clover requires 500 pounds of water for each pound of dry hay, it would require 1000 tons of water for a 2½-ton crop of field-cured clover hay having a moisture content of 20 per cent. This would be approximately equivalent to a 9-inch rainfall. Table V gives the approximate water requirements of some of the more common agricultural crops.

The water supply is at least partly under the farmer's control. In the humid sections, where injury by drought is uncommon, and never very serious, little attention is given to the conservation of soil moisture. Where crops may be injured either by an inadequate rainfall or by a poorly distributed one, more attention is paid to the efficient utilization of the available supply. In these subhumid or semi-arid climates, systems of dry-land farming have been developed. They provide for the conservation of the water supply by lessening the surface runoff and the evaporation from the soil, by the choice of drought-resisting crops, and by moderately light rates of seeding. In the more arid sections, irrigation must be resorted to, or the land left unfarmed. Even in the

TABLE V

Water Requirements of Crops

(Average number of pounds of water required per pound of dry matter.*)

| | |
|---|---|
| Alfalfa | 831 |
| Barley | 534 |
| Buckwheat | 578 |
| Corn | 368 |
| Cotton | 646 |
| Flax | 905 |
| Millet | 310 |
| Oats | 597 |
| Rice | 710 |
| Rye | 685 |
| Sorghum | 322 |
| Sugar beets | 395 |
| Wheat | 513 |

* J. Warren Smith. "Agricultural Meteorology," The Macmillan Co.

humid regions there are few growing seasons in which the yields of some crops are not reduced because of an insufficient moisture supply at some period during their growth.

**E. Nourishment.** The yield of crops, at least in the humid sections of the United States, is dependent more often on the plant-food supply than on any other controllable soil factor. Even though a relatively small proportion of the weight of plants is composed of the plant-food constituents coming from the soil, nevertheless, a deficiency of some one of these, generally nitrogen, phosphoric acid, potash, or lime, controls the yield of field crops.[3]

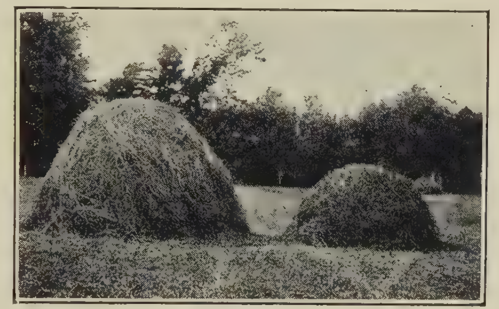

FIG. 31. FERTILIZED *vs.* UNFERTILIZED HAY.

The yield of crops, at least in the humid sections of the United States, is dependent more often on the plant-food supply than on any other soil factor.

Plants secure carbon and oxygen from the air, hydrogen and oxygen from water, and all other required chemical elements from the soil. Certain crops, known as *legumes,* have the power when inoculated of utilizing the nitrogen of the air. The soil supply of this element is being replenished to some extent by the addition of atmospheric nitrogen both through the activity of soil organisms and by rain water. Sulfur is also added by rain.

The farmer is most concerned with the three common plant-food elements of fertilizers—nitrogen, phosphorus, and potassium; and with calcium and magnesium, the two most important elements of agricultural lime. The commercial fertilizer and lime industries have been developed to meet the farmer's demand for these two materials. The farmer himself has developed fertilizer and lime practices based largely on the crop and soil needs for this group of chemical elements.

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[3] See General Information at end of Chapter for discussion of the feeding of plants.

**F. Negative factors.** In addition to the essential positive factors of growth, there are several negative factors. Unless controlled by the farmer, these retard the growth and lessen the production of crops. This group of negative factors includes weeds, crop diseases, insect injury, and the like. They often give the farmer more concern than the positive factors of crop production. Success in farming necessitates the control of weeds and of insect pests. Every farm-reared boy at one time or another has had real experience with the weed problem. Enormous sums of money have been expended in determining practical methods for the control of the injurious crop diseases and insect pests of the farm. A veritable army of scientists is making this problem a life work. Farmers find that even the most approved control methods are tremendously expensive, and at best only partly effective in combating the ravages of insects and crop diseases.[4]

The yield of crops may be said to depend on the farmer's supplying the essential positive factors of growth and at the same time controlling the injurious or negative factors. The final yield of a given crop depends often on the factor supplied the least adequately, or controlled the least effectively. Such a factor is known as the *controlling factor* of growth. Take, for example, the corn crop. Assume the soil to be in excellent physical condition, the season favorable, weeds kept down by thorough cultivation, and no serious disease or insect injury present. The yield under such conditions would be expected to depend on the supply of plant-food which would be, in this case, the controlling factor of growth or yield. The growth of corn, however, may be controlled by a deficiency of any one of at least three different plant-food elements of the soil. Normally they would not be equally deficient. Assume further that the soil in which the corn is grown is adequately supplied with potassium, and that a liberal amount of phosphorus is supplied in superphosphate. Nitrogen, then, would be the deficient plant-food constituent for corn, and it would largely determine the growth and final yield. Under such conditions nitrogen would be considered the controlling element of growth or of yield.

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[4] See "Crop Production and Soil Management," by J. F. Cox, published by John Wiley & Sons, for control of weeds and crop pests.

The principle of a single factor or of a single element, as the case may be, controlling growth is figuratively illustrated by a tub with staves of unequal length. The amount of water which the tub will hold depends on the height of the shortest stave. In the same way, the yield of crops is dependent on the supply of the deficient factor or the deficient element of growth.

FIG. 32. FIELD OF POOR COTTON. (N. C. Agr. Exp. Sta.)

The production of the same crop on a field year after year is an unsound practice.

The successful production of crops is largely dependent on the farmer's ability to supply the material or to rectify the condition which controls the growth of his crops. Profit from the farm business necessitates that this be done not only effectively but also economically.

**G. Crop rotation.** The production of the same crop on a field year after year is an unsound practice. Unless liberally fertilized, a soil becomes depleted with such continuous cropping, and insect injury and crop disease are more difficult to control. Farm labor, horses, and machinery cannot be used to advantage unless several different crops are produced. Cultivated crops like corn, potatoes, and beans do best where a sod has been plowed under, whereas alfalfa should be preceded by a cultivated crop. Economically, it is unwise to depend on a single crop because the failure of that particular crop might result in a complete loss of income for the year. Where livestock farming is followed, it becomes necessary to produce several of the different feed crops each year.

FIG. 33. CLOVER FIELD. (Agronomy Dept., Ill. Agr. Exp. Sta.)

From the standpoint of the soil, the three-year rotation, in one year of which clover is grown, has much to be said in its favor.

In the production of field crops, a rotation varying from three to six years should generally be followed. The four-year and five-year rotations are most common on the better farms in the grain and hay sections. From the standpoint of the soil, the three-year rotation, in one year of which clover is grown, has much to be said in its favor. A good field-crop rotation should include one cultivated crop and one legume crop. Through proper cultivation, weeds may be killed the year the land is in a cultivated crop. The legume crop is essential as an economic means of supplying nitrogen for the other crops of the rotation. In order that the legume may function most efficiently in adding atmospheric nitrogen to the soil, it should either be plowed under as a green-manure crop, or fed to livestock and the farm manure returned to the land.

In sections where grain is produced as a cash crop, the tendency has been to grow these crops continuously. To almost the same extent this has been true with cotton. The rapid depletion of many soils has resulted from the production of such soil-depleting crops as corn, cotton, oats, and wheat to the more or less complete exclusion of such soil-building crops as alfalfa, clover, and grass. In the production of vegetables on high-value land, it has been found necessary to utilize soil-building cover crops as green manure, which frequently can be grown the same year as the cash vegetable crop. Fortunately, with vegetables or other high-value crops, the returns justify the application of sufficient fertilizer to prevent the depletion of the soil supply of plant-food. The soil-conservation problem in connection with the production of high-value crops is largely one of maintaining the soil organic-matter supply and of preventing the loss of topsoil by erosion.

The kind of crops in the rotation, as well as the length of the rotation, will depend on many factors, including the following: crops adapted to the climate and soil, feed requirements of the farm animals, distance from market, and the marketing facilities for the different crops. On level land not subject to erosion, rowed crops may be grown frequently in the rotation, but, on hilly farms, follow long rotations consisting largely of hay and pasture crops.

## 2. Fertilizing Different Crops [5]

Crops vary in their plant-food requirements. The fertilizer application should take into consideration the character of the crop as well as of the soil. In fact, fertilizer recommendations are commonly made on the basis of different crops rather than different soils, and brands of factory-mixed fertilizer based on the needs of the individual crops are available.[6]

There is, however, no best composition or best amount of fertilizer for an individual crop or class of crops. Factors other than the crop requirement influence the profit that the farmer can expect from fertilizer. Among such factors are the character of the soil; the rotation, including green-manure crops; the amount and frequency of the manure application; tillage practices followed; the cost of fertilizer; and the price received for the crop produced. In fact, the composition of the fertilizer will necessarily depend somewhat on the amount to be applied, or rather, on the size of the fertilizer investment on the acre basis. Although these limitations make it impossible to determine definitely the most advantageous fertilizer application for a given crop or a particular soil, certain fundamental principles underlying the economic fertilizing of vegetables, fruit, and field crops are well established.

**Procedure:**

A. Compare fertilizing practices on the crop basis.
B. Utilize the "farm-fertilizer factory."

**A. Compare fertilizing practices on the crop basis.** **(1)** *Greenhouse crops.* In the fertilization of greenhouse soils, the cost of fertilizer need hardly be considered. It is a question of supplying all the plant-food that will in any way be beneficial in yield, quality, or date of maturity of the crop; for so long as benefit is secured, the investment may be expected to return a profit. The rate of application is dependent more often on the amount that can be applied safely without injuring the crop than on that which will return a profit on the investment. It is purely a question of plant nutrition and not of economics.

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[5] This discussion of fertilizing different crops is very general in character. It is inclusive enough to indicate the relation of crop composition to fertilizer requirement and should stimulate interest in the crop factor as related to soil management. Fertilizer practices are developed more fully in Chapters IX to XII.

[6] See General Information at end of chapter for the requirement of different crops.

Fig. 34. Lettuce Growing in Greenhouse. (Horticultural Dept., Ill. Agr. Exp. Sta.)

In the fertilization of vegetables and flowers grown under glass, a complete fertilizer can always be justified.

Obviously, then, in the fertilization of vegetables and flowers grown under glass, a complete fertilizer can always be justified; for invariably some benefit may be expected from each of the three constituents. While the phosphoric acid should be proportionately higher in comparison to the nitrogen and potash than is indicated by crop composition, it should be proportionately lower than where crops are grown less intensively.

It is impractical and uneconomical to depend on legume crops as a source of nitrogen. Manure, or other forms of organic matter, should be used even though costly; for the value of the crop produced will justify large expenditures for soil treatment. However, organic matter should be supplied on the basis of producing in the soil the most favorable physical and biological conditions for the crops grown rather than to supply nutrients. It is cheaper to supply the plant-food needs in the form of commercial fertilizers and purchased manure than to secure them by means of legumes and green manures. In general, use a fertilizer with approximately equal amounts of nitrogen, phosphoric acid, and potash, and supplement with additional nitrogen when necessary.

Fig. 35. A Home Vegetable Garden. (Vegetable Gardening Dept., N. Y. State Col. of Agr.)

A fertilizer with the proportion of two parts of phosphoric acid to one each of nitrogen and potash is well adapted to the vegetable crops.

(2) *Vegetables.* In the fertilization of the vegetable garden, the use of a complete commercial fertilizer is justified. The market gardener and the trucker find that for maximum

returns a fertilizer containing all three constituents is necessary.

A fertilizer with the proportion of one to two parts of phosphoric acid to one each of nitrogen and potash is well adapted to the vegetable crops. Use a complete fertilizer of this type in amounts of from 1000 to 2000 pounds to the acre, depending on concentration, where vegetables are grown intensively. With muck or peat soils, use relatively more potash and less nitrogen.

Farm manure has been found especially beneficial on the home garden and is highly valued by commercial growers. When it is used, increase somewhat the proportion of phosphoric acid in the fertilizer, and when liberal applications are made, reduce the nitrogen or leave it out of the fertilizer entirely. In some instances, superphosphate along with the manure will give satisfactory yields.

Lime, in amounts to reduce excess acidity of the surface soil, has been found imperative for the successful production of vegetables. Lime should not be used in excessive amounts since most vegetables grow best on a slightly acid soil. For watermelons leave the soil in an acid condition, and use precaution in the liming of potato land because of scab.

When vegetables such as potatoes, peas, cabbage, and beans are grown as cash crops on general farms in the regular field-crop rotation, a phosphatic fertilizer material up to a certain rate of application, used with manure, will give more economical results than will mixed goods. However, if manure is not used, there should be a reasonably heavy application of complete fertilizer. Irrespective of the commercial fertilizer used in vegetable-crop production, either in field or garden, it is important that a high soil organic-matter content be maintained through the return of farm manure or green-manure crops, or both.

(3) *Cotton.* Cotton generally requires a complete fertilizer for best results. As comparatively little manure is produced on cotton farms, the nitrogen needs of cotton, which

FIG. 36. A FIELD OF GOOD COTTON. (N. C. Agr. Exp. Sta.)

Apply 600 to 1000 pounds to the acre of a high-analysis, complete fertilizer for cotton.

FIG. 37. A SOD ORCHARD.

For orchards in sod make liberal applications of nitrogenous fertilizer or of farm manure.

are relatively high, must be met largely through the growing of legume catch crops, and the application of nitrogenous fertilizers. The fact that the soils of the Cotton Belt are so commonly deficient in organic matter makes it even more imperative that cotton fertilizer contain considerable nitrogen. Apply 600 to 1000 pounds to the acre of a high-analysis complete fertilizer for cotton.

(4) *Orchards.* Experiments with fruit indicate that in general an adequate supply of plant-food can be secured from the soil. The plant-food most often needed by tree fruits is nitrogen. Base the use of the mineral plant-foods, phosphoric acid and potash, as well as that of lime, on the requirements of the cover crops rather than on the needs of the trees themselves. Where certain fruits are grown on sandy or gravelly soil, or others very deficient in available minerals, phosphoric acid and potash may be of direct benefit to the trees.

Farm manure has been found an excellent fertilizing material for fruit trees, but unless produced on the farm, it is generally too expensive. When properly used, it will give good results by itself, as far as the trees are concerned; but when one considers the needs of the orchard cover crops and the possibility of retarding the maturity of the fruit by the use of manure alone, the practice of reinforcing the manure with a phosphatic fertilizer is justified. On most fruit farms, little manure is produced, and any that is available can, with few exceptions, be used to better advantage on other crops.

Whether or not fertilizer nitrogen is essential will depend largely on whether the orchard is tilled or in sod. Surface soils that are well supplied with organic matter are capable, when the orchard is thoroughly tilled, of supplying adequate available nitrogen to meet the need for both tree growth and fruit development. On soils less well supplied with organic matter, fruit will respond to nitrogen, and when in the bearing stage will return a profit from an investment in a soluble nitrogenous fertilizer. Where the nitrogen needs are partly or entirely met through tillage, the soil supply of organic matter and of nitrogen is being utilized and ultimately will become depleted unless adequate provision is made to renew the supply by growing cover crops and plowing them under as green manure.

With sod orchards, the timothy or other grasses are such heavy and efficient feeders on the soil nitrogen that the trees are unable to secure enough for normal growth or fruitage. Consequently, for orchards in sod, make liberal applications of nitrogenous fertilizer or of farm manure. With an alfalfa or clover sod the need for this additional nitrogen is greatly lessened.

Fig. 38. An Alfalfa Field.

Usually a phosphatic fertilizer is the greatest need of legumes, and not infrequently it is the only fertilizer treatment that can be justified for the field-grown legume roughages.

(5) *Legumes.* Encourage the legumes to draw on the atmosphere for their nitrogen needs. This means, first of all, that the crop should be thoroughly inoculated. If necessary, inoculate the seed or soil and thereby obviate the need of applying nitrogenous fertilizers. The legumes, being heavy feeders on the mineral elements, should receive liberal amounts of phosphoric acid. If the soil does not furnish sufficient potash, this also should be supplied in the fertilizer. Beans,

peas, peanuts, and some other legume cash crops justify the use of fertilizer nitrogen as well as phosphorus and potash. On very poor soils, a complete fertilizer may be necessary to the successful establishment of legumes. Usually a phosphatic fertilizer is the greatest need of the legumes, and not infrequently it is the only fertilizer treatment that can be justified for the field-grown legume roughages.

Lime has been found to be absolutely essential for such legumes as red clover and alfalfa throughout much of the eastern half of the United States. In the Pacific Coast states sulfur is generally beneficial for alfalfa.

(6) *Pastures and lawns.* Ordinarily, complete fertilizers are entirely too expensive for use on pastures. Some nitrogen and potash are returned to the land in the manure from the animals pastured, and sometimes a dairy or livestock farmer is justified in applying manure to the permanent pasture land. White clover or other legume plants in the pasture will aid in furnishing nitrogen for the true grasses. Phosphoric acid is generally the first plant-food need of permanent pastures. It is commonly supplied in the form of superphosphate, but basic slag or rock phosphate may be used. Under some conditions potash will pay, but the nitrogen needs must be met, except in intensive systems of pasture fertilization, through some method that is more economical than is possible with mixed commercial fertilizers.

Lime can be used advantageously on many of the permanent pastures in the eastern third of the United States. Unless lime is used where the pasture soil is extremely acid, Kentucky bluegrass and white clover will not thrive. However, there are many good pasture grasses and some pasture legumes which will grow well on soils that are too acid for red clover.

In the fertilization of lawns, the object is not to realize a profit but to secure and maintain the desired turf, and the actual outlay for fertilizer is not of prime importance. Consequently, the use of a complete fertilizer in rather liberal amounts is justified. Such a fertilizer should be similar in composition to that used on the vegetable garden. For a small lawn the nitrogen and potash content of the fertilizer may equal that of phosphoric acid, and the three plant-food constituents may be applied in the proportion suggested for greenhouse crops. Fertilizer should be applied to a lawn early in the spring just as soon as the grass shows signs of growth.

FIG. 39. BLUEGRASS AND WHITE-CLOVER PASTURE. (Agronomy Dept., Ill. Agr. Exp. Sta.)

**Phosphoric acid is generally the first plant-food need of permanent pastures.**

An additional application may be made later in the season if the need becomes apparent. Lime may be required in the establishment of a bluegrass and white-clover lawn on acid soils. Certain grasses adapted to sour soils in the northern states will produce a finer-textured turf than will bluegrass. The bent grasses are well suited for lawns, especially where the soil is very acid. In the southern states carpet and Bermuda grass are the common lawn grasses. Both grow well on acid soils.

(7) *Grain, silage, and hay crops.* The fertilization of field crops grown for grain and forage presents a problem entirely different from that confronting the market gardener, the horticulturist, or even the cotton planter. Here the question of possible profit from the investment becomes paramount. It is not a question of supplying all the fertilizer that will in any way benefit the crops, but rather of meeting their needs with the minimum investment in commercial fertilizers.

FIG. 40. FIELD OF GOOD WHEAT. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Profitable grain and hay production necessitates the establishment of soil-management practices that will eliminate the need of expensive commercial nitrogen and mixed fertilizers.

The general grain, hay, or livestock farmer must necessarily depend to a considerable extent on clover and alfalfa, along with farm manure, for supplying nitrogen and potash for the crop and for replenishing the soil supply. Lime must be supplied to counteract excess soil acidity and assure success with clover or alfalfa. The nitrogen needs of these field crops, which at best give relatively low acre returns, cannot be economically secured through commercial fertilizer. This nitrogen must come largely through the growing of legumes and the return to the land of farm manure. Where the nitrogen needs are met in this economical way, a sufficiently large available potash supply will often be maintained to meet the potash requirements for the grain and hay crops. As a result, phosphoric acid becomes the outstanding plant-food requirement, and is often the only one that can be used with profit on land that is regularly manured, but if manure is not applied, potash will be needed. If a long rotation is followed without soil-improving legume crops, or these crops grown infrequently, a complete fertilizer relatively high in nitrogen will be required for satisfactory yields. A light rate of application of a mixed fertilizer may be made to advantage in the row at the time of planting, even where adequate superphosphate and manure have been applied for the rotation. Nevertheless, profitable grain and hay production necessitates the establishment of soil-management practices that will largely eliminate the need of expensive commercial nitrogen and mixed fertilizer, and at the same time make possible good yields through the use of a phosphatic fertilizer alone or in addition to lime.

**B. Utilize the "farm-fertilizer factory."** Irrespective of the type of farming, the importance of farm-produced plant-food and of the return to the soil of adequate amounts of farm-produced organic matter should be appreciated by all farmers. In animal manure, green manure cover crops, and legumes, particularly the clovers, including alfalfa, farmers have the equivalent of a fertilizer factory of tremendous capacity. Economic systems of fertilization, so necessary to the profitable production of crops, can come about only through the adequate utilization of this "farm-fertilizer factory" and the intelligent and efficient supplementing of its product with lime and commercial fertilizers. Purchased fertilizer should supplement and not replace farm sources of plant-food.

## GENERAL INFORMATION

### 1. How Plants Feed

The application of fertilizer and manure, as well as many of the other important practices in the management of soils, furnishes available plant-food for the growth of crops. Meeting the crops' demand for nourishment is an outstanding requirement for successful production. The farmer is so much concerned with the feeding of crops that a clear understanding of certain functions of plant nutrition is of real interest to him. In other words, it is to his advantage to know how crops feed.

Energy is required for the processes of plant growth. This energy is supplied by sunlight which plants are able to utilize and which they require for producing true plant-food compounds from the chemical elements supplied by the soil, water, and air. From the germination of the seed to the ripening of the crop, the life processes within the plant are very complex and difficult to understand. They will be outlined briefly and as simply as possible.

**A. Germination of the seed.** Growth starts with the germination of the seed. The seed itself consists of the growing part, called the embryo; a supply of stored nourishment either in the cotyledons, a part of the embryo, or in the endosperm joined to the embryo; and a covering, or seed coat. The stored food in the seed consists of various complex chemical compounds which are very concentrated. As long as the seed is properly stored in a dry place, it will retain its germinating ability for a prolonged period. But even though the seed of some crops will retain a high percentage of germination for several years, it has been found desirable to depend, so far as possible, on fresh seed—that is, seed produced the preceding season.

Three factors are essential for germination: (1) favorable moisture content of the seed; (2) oxygen supplied as air; and (3) a proper amount of heat. All three essentials must be met before conditions become favorable for germination. If water is supplied without sufficient heat or without air, the seed will not only fail to germinate, but the germinating power will be destroyed. Farmers frequently have this experience with corn and other spring-planted crops in cold, wet springs when the seed rots in the ground, and replanting is necessary for a good stand. The seed-bed should be well drained and aerated so that it will warm up early in the season. In the germination process, water is first absorbed. This water combines chemically with the stored food supply and is transported to the embryo. Thus germination and growth begin. The plumule pushes upward toward the surface while the root tissues develop and extend downward. The supply of stored food material in the seed is adequate to nourish the seedling until root and leaf development has progressed sufficiently to enable it to secure its nourishment from the soil, water, and air.

**B. The soil's contribution.** The root systems of plants differ materially in character. Some plants, such as beets and carrots, have fleshy roots; others, such as the grains and the grass crops, have fibrous roots; still others, including alfalfa, have tap roots. All root systems are similar in that they consist of the main roots, which penetrate the soil and hold the plant in place, and of the small, almost invisible root hairs which thickly cover all new root growth. These root hairs are not young, immature roots, and they never develop into roots proper. On the contrary, each root hair is simply a single, elongated cell, with membranous walls through which water passes readily. They are located near the tip ends of the roots proper, and as the root system expands new root hairs are formed, so that the plant is constantly drawing on new areas of soil for nutrients.

The essential plant-foods furnished by the organic matter and the rock particles of the soil, consisting largely of nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, must be dissolved in the soil water before they can enter the plant. These root hairs excrete carbon dioxide ($CO_2$) in the form of a gas which combines with the soil water in the immediate vicinity of the root hairs and increases its dissolving capacity. In this way the plant may increase slightly the availability of the nutrients of the soil. It has been found that air is necessary for the proper functioning of the root system of the plant, and when it is completely excluded, as it virtually is in a water-logged soil, normal growth ceases.

**C. The function of water.** As the soil solution comes in contact with the root hairs, it passes through the semi-permeable membrane and combines with the cell solution. This passage of soil water is dependent largely on osmotic pressure. The movement of liquids through permeable membranes is called *osmosis,* and is always from the less concentrated to the more concentrated solution. The cell sap of the root hairs, therefore, must remain more concentrated than the soil solution for the normal movement to continue. The salts are utilized in growth, and water transpires into the atmosphere. The soil solution under some conditions may become more concentrated than that in the plant; then, the plant wilts. Alkali soils may have a solution of soluble salts so concentrated that vegetation cannot grow. Through an excessive application of soluble fertilizer, the soil solution may temporarily become more concentrated than that within the plant; wilting then occurs, and the farmer refers to the resulting injury as the burning effect of the fertilizer.

This absorption of water takes place as long as the total concentration of the solution within the root hairs is greater than that in the soil. The nutrients are absorbed more or less independently of the water itself. As they are dissolved in the soil solution they become diffused into their respective ions. In the process of absorption there is at least a tendency for the ions of a given nutrient to establish an equilibrium between soil and root-hair solutions. Thus, a particular nutrient may be absorbed or rejected by the plant, depending on the concentration of the ions of the nutrient. This absorption of the nutrients from the ionized soil solution, independent of the absorption of water, is the explanation for the so-called "selective power" of plants for the soil nutrients.

The absorbed soil water with its dissolved nutrients does not remain in the cells of the root hairs. It passes on from cell to cell through the roots and finds its way up through the plant to the leaves. Here, it performs the additional function of dissolving carbon dioxide, and makes possible its diffusion throughout the plant. Water is constantly escaping through the stomata into the atmosphere. The process by which water leaves the plant is called *transfusion.* Thus, the greater portion of the water entering the roots completes its nutritional functions of transporting and diffusing nutrients, after which it returns to the atmosphere.

**D. Plant-food from the air.** Plants, like animals, breathe. Through respiration, living plants are constantly giving off carbon dioxide, just as are animals. However, with plants, this normal respiration is of less importance than a similar process called *photosynthesis,* in which the carbon dioxide of the air is utilized for the formation of starch in the green parts of the plant.

The under side of the leaves of plants is covered with small openings called *stomata.* These also occur to a lesser extent on the upper side of leaves and on the surface of other green tissues. Carbon dioxide of the atmosphere is diffused through the stomata. It is dissolved by the water within the plant, and is then diffused throughout the cell structure where the carbon and oxygen are utilized in the formation of new compounds of growth. The oxygen is only partly used, the remainder passing back into the atmosphere.

Even though the carbon dioxide supply of the atmosphere is relatively small and is being constantly absorbed by plant life and synthesized into organic compounds, the amount remains more or less constant. This happens because the supply constantly is being replenished as organic matter, and is broken down as the result of the activity of the microorganisms of the soil or of the digestion by animals, or by burning. There appears to be a well-balanced carbon-dioxide cycle between the air and the earth itself.

Chlorophyll absorbs the sun's rays and stores the energy in more or less stable forms to be used as food for all animal life. As a source of power and heat it plays an essential role in the functioning of all forms of life. It is necessary for the production of carbohydrates, and protein compounds, also.

Carbon and oxygen are important constituents of plants and, along with hydrogen, make up about 98 per cent of their green weight.

**E. Starch formation.** Leaves, and the stems of many plants, have a characteristic green color which is due to a coloring matter, called chlorophyll, occurring in the plant tissues. It is very similar in chemical structure to that of the red corpuscles in the blood of animals. Chlorophyll is formed only in the presence of sunlight; it has an important function in the nutrition of the plant. It is this green coloring matter which makes it possible for the plant to take carbon from the atmosphere. Chlorophyll enables the plant to absorb energy from the sun's rays and thus makes possible certain complex chemical changes within the leaves, in which the carbon dioxide from the air is combined with the water from the soil, finally forming starch or similar organic compounds. After undergoing additional chemical change, as a result of which soluble, sugary compounds are formed, this organic material is diffused to the growing parts of the plant. Here it is utilized for the building of new plant tissue with its ever-complex chemical make-up.

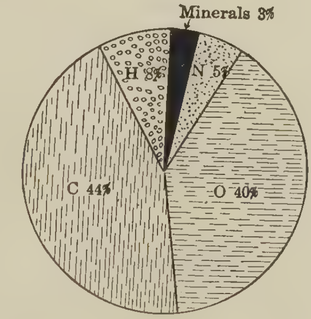

FIG. 41. COMPOSITION OF PLANTS.

The average composition of the dry matter in plants.

In connection with photosynthesis it is interesting to appreciate its importance, not only to plant life, but to all animal life as well. It is the process by which all energy is supplied either directly or indirectly for all forms of life from the microscopic bacteria to the largest and most advanced types of plants and animals. As the result of photosynthesis, vast stores of energy furnished by the sun's rays have been stored as an accumulation of organic material. Today man is largely dependent as a source of energy for the many needs of modern civilization on the energy supplied by the sun in the form of wood, coal, oil, and gas. The only other known sources of energy are water and wind.

Plants store up varying amounts of nutrients in their root systems. This plant-food supply is spoken of as *root reserve.* With certain perennial crops, such as alfalfa and the grasses, it is important that cutting or grazing be delayed until an adequate root reserve has been established to provide nutrients to supplement the soil supply for the new top growth. Too close grazing of pastures or too frequent cutting of perennial hay crops may so lessen the root reserve as to reduce total annual yields.

**F. Composition of the plant.** The growing plant contains, in addition to an average of 75 per cent by weight of water, approximately 25 per cent of dry matter, which in turn is made up of 44 per cent of carbon, 40 per cent of oxygen, 8 per cent of hydrogen, and 8 per cent of nitrogen and the mineral elements combined. When plants are burned, only the mineral matter remains in the ash. It normally constitutes about 3 per cent of the weight of the dry matter, or a little less than 1 per cent of the total weight of the green plant. Figure 41 shows graphically the average composition of dry matter in plants.

**G. Function of nitrogen.** Nitrogen is particularly needed by plants for vegetative growth. A nitrogen deficiency is sure to cause stunted growth of the whole plant structure. The nitrogenous compound of plants is known as *protein.*

Besides nitrogen, the numerous and extremely complex protein compounds of plants contain carbon, hydrogen, and oxygen. They generally contain such mineral elements as sulfur and phosphorus and often others, such as calcium and iron. The proteins occur in colloidal form, and are capable of absorbing water. They make up a much larger proportion of the tissue of animals than of plants. Even though the chemical composition is entirely too complex for consideration here, it is of importance to appreciate that the nitrogen and much of the phosphorus of plants occur in the various protein compounds.

The protein is the expensive constituent of feed for livestock. In fact, farmers find that nitrogen is the expensive constituent in both feeds and fertilizers. Nitrogen influences the color of the green chlorophyll. When it is deficient, the leaves are a light, sometimes yellowish green; but when there is an abundance of nitrogen, vegetation is of a characteristic dark-green color. Excessive amounts of nitrogen lengthen the growing season of a crop, retarding noticeably the date of maturity. This may be very undesirable with certain crops in a short season. Excess nitrogen also weakens the stalks, and as a result serious lodging may occur before the crops are ready for harvest.

**H. Phosphorus.** Phosphorus occurs largely in the seed of plants. When it is deficient, the production of seed or the yield of the grain crops is reduced. Phosphorus is a common constituent of most of the protein of plants, and has been found to stimulate early growth. Its practical effect on crop growth is in many respects the opposite of that of nitrogen. It not only increases seed production rather than vegetative growth, but also hastens maturity and reduces the lodging of farm crops.

**I. Potassium.** Carbohydrates, including sugars, starch, and cellulose, are compounds composed of carbon, hydrogen, and oxygen. Potassium, which is a constituent of all plant tissue, appears to play an important part in photosynthesis and in the formation of carbohydrates. Starchy crops such as potatoes require especially large amounts of this element for their normal growth. The sugar content of the sugar beet is influenced favorably by a large supply of available potassium, or potash.

**J. Calcium, magnesium, and lime.** Both calcium and magnesium have been found to function in connection with the nutritive process associated with carbon fixation and the formation of tissue-building compounds. They are also known to be of value in counteracting or neutralizing acids which are a by-product of certain functions of growth. Some plants, such as alfalfa and sweet clover, require especially large amounts of calcium for their normal development. Magnesium in some unknown way appears to influence the effectiveness of phosphorus. Sulfur is a constituent of most protein, and iron is an essential for chlorophyll formation.

**K. The minor nutrients.** Of the other elements important in plant growth, little need be said as to their functions. In fact, the exact essential functions of some are not definitely known. Silicon appears to be an essential constituent of cellulose; sulfur seems essential in the formation of certain protein compounds; and iron functions in the formation of chlorophyll, as also may aluminum and manganese. Boron, copper, and zinc are known to be needed in very small amounts, but their functions are not definitely understood.

Certain plant diseases are recognized as nutritional in nature, owing most often to deficiency of some one of the nutrients. Among these numerous nutritional diseases may be mentioned chlorosis, browning and whiptail of cauliflower, internal black spot of beets, and cracked stem of celery.

**L. Supplying nutrients.** In farming, one must consider how best to supply the nutrient needs of the crops. The function of the different plant-food elements is not only of interest but of vital importance in successful crop production. Crop yields are largely dependent on the efficiency with which the plant-food requirements of the various crops are met. Although the different farm crops secure their plant-food in a similar way, they differ widely in the amounts of the different nutrients required for their normal growth, as well as in the amount which can be supplied economically by fertilizers. Effective systems of fertilization must take into consideration not only the requirements for the growth of plants in general, but also the particular plant-food needs of each important group of agricultural crops, and the economic means of supplying such deficiencies.

## 2. What the Different Crops Require

**A. Plant-food requirement.** Even though plants vary in their plant-food requirements, it should not be assumed that the fertilizer application can be based on the crop requirement alone. The relation of soil composition to fertilizer practices has been emphasized, but, as already explained, the results of soil chemical analysis are in themselves inadequate as a basis for fertilizer recommendations. In the same way, a knowledge of the plant-food requirements of the various crops is not a sufficient basis upon which to determine the most profitable fertilizer treatment to use. Nevertheless, knowledge of crop composition is of real value in working out practical systems of fertilization for the more important groups of crops.[7]

It is of interest in this connection to compare the average composition of the crop with the average composition of soils, farm manure, and complete commercial fertilizers. Such a comparison shows the tabulated relative average amounts of

| | Nitrogen | Phosphoric Acid | Potash |
|---|---|---|---|
| Crop requirement......... | 3 | 1 | 2 |
| Soil composition.......... | 2 | 1 | 4 |
| Farm manure composition . | 5 | 3 | 5 |
| Fertilizer composition..... | 1 | 2 to 3 | 1 |

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[7] See General Information at end of Chapter VII for simplified tests for determining crop deficiencies.

nitrogen, phosphoric acid, and potash in crops compared with that in soil, farm manure and mixed fertilizer of average composition. The amount of plant-food contained in the more important crops is given in Table VI.

TABLE VI

PLANT-FOOD REQUIREMENTS OF AGRICULTURAL CROPS *

(Pounds per Acre, Harvested Crop)

| Crop | Yield | Nitrogen (N) | Phosphoric Acid ($P_2O_5$) | Potash ($K_2O$) | Lime (CaO) | (MgO) |
|---|---|---|---|---|---|---|
| Alfalfa | 4 tons | 185 | 45 | 175 | 150 | 47.0 |
| Apples | 500 bu. | 35 | 12 | 44 | 33 | ....... |
| Barley | 50 bu. | 60 | 25 | 50 | 10 | 7.5 |
| Beans | 30 bu. | 100 | 30 | 60 | ....... | ....... |
| Buckwheat | 40 bu. | 44 | 20 | 35 | 20 | 20.0 |
| Kentucky bluegrass | 1 ton | 24 | 8 | 31 | ....... | ....... |
| Cabbage | 20 tons | 135 | 33 | 130 | 67 | 10.0 |
| Clover (Red) | 2½ tons | 100 | 25 | 85 | 70 | 22.0 |
| Corn | 75 bu. | 115 | 42 | 85 | 21 | 14.0 |
| Cotton | ½ ton | 130 | 50 | 100 | 138 | ....... |
| Oats | 65 bu. | 60 | 25 | 60 | 16 | 12.0 |
| Peas | 25 bu. | 90 | 20 | 54 | 78 | ....... |
| Peanuts | 1 ton | 85 | 15 | 50 | 57 | ....... |
| Potatoes | 300 bu. | 125 | 35 | 160 | 5 | 9.0 |
| Rye | 35 bu. | 52 | 24 | 40 | 12 | 8.0 |
| Soybeans | 25 bu. | 125 | 40 | 60 | 60 | 35.0 |
| Timothy | 2 tons | 50 | 20 | 60 | 14 | 7.0 |
| Tobacco | 1½ tons | 105 | 25 | 150 | 65 | ....... |
| Wheat | 35 bu. | 60 | 25 | 35 | 8 | 8.0 |

* Plant-food in root growth not included.

**B. Root and tuber crops.** The root and tuber crops have a rather high potash requirement. Particularly is this true of the Irish potato, for which, owing to the high starch content of the tubers, potash is needed in relatively large proportion compared to other plant-foods. The composition of the root crops does not indicate a particularly high phosphorus requirement, but in general root crops respond to liberal applications of phosphatic fertilizers. It is interesting to note that turnips have been found to give markedly increased yields when fertilized with phosphoric acid, whereas carrots show little response to the same treatment. The total nitrogen requirement of the root and tuber crops is not great, and care must be exercised in their fertilization not to supply excessive amounts of nitrogen. If too much is applied, a large top growth will result at the expense of root or tuber development. In potatoes this condition is designated as "the crop going to tops." The root and tuber crops in general have rather a restricted root system. They are not considered especially efficient in utilizing the soil supply of plant-food and consequently require liberal fertilization.

**C. Legumes.** The legumes are particularly rich in nitrogen. When they are dependent on the soil for their supply, large amounts of available nitrogen are necessary for their normal growth. However, when inoculated, they are able to draw on the soil air for their nitrogen needs. Inoculation material is far less expensive than nitrogenous fertilizer, and farmers have found that, if the soil is not supplied with the proper bacteria, inoculation for legumes becomes necessary for their economic production. Even though legumes have a high nitrogen requirement they become, when inoculated, a valuable source of nitrogen for farmed soils. In certain alkali soils of the western states, where the soluble nitrogen content is excessive, such legumes as alfalfa and sweet clover have been employed to reduce the nitrogen supply of the soil. Under such conditions, legumes take little or no nitrogen from the atmosphere.

The legume crops have a relatively high mineral plant-food requirement. Their growth may be controlled by a deficiency of phosphoric acid, potash, or lime. In some instances, more particularly in the far West, sulfur has been found to be highly beneficial to alfalfa. The deep-rooted legumes have the capacity of drawing on the subsoil to a considerable extent for these mineral constituents, but, even so, their successful production generally necessitates the use of mineral fertilizers. Very often such legumes as clover and alfalfa require lime to neutralize the acidity of soils.

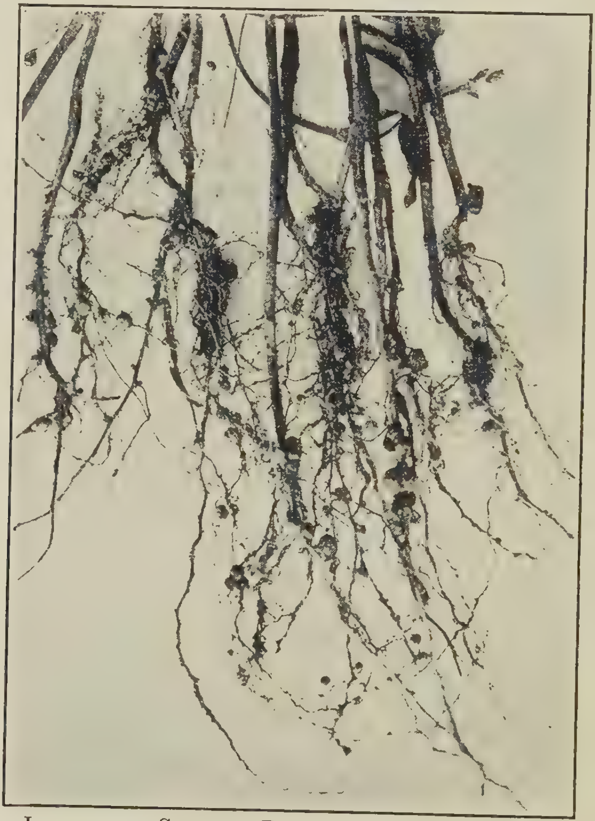

Fig. 42. Inoculated Soybean Plants. (Agronomy Dept., Ill. Agr. Exp. Sta.)

When inoculated, legumes are able to draw on the soil air for their nitrogen needs.

**D. Vegetables.** The vegetables, other than the root and tuber crops, have a relatively high nitrogen requirement. This is particularly true of leafy vegetables such as spinach, lettuce, and celery. Tomatoes and some of the other fruiting vegetables require relatively less nitrogen in the fertilizer. The garden legumes, such as peas and beans, when inoculated, can draw on the air for much of their nitrogen. In the practical fertilization of vegetables, it has been found profitable often to apply plant-food in amounts well in excess of the crop requirements as indicated by their chemical composition. Vegetables vary in their need for lime. Cabbage, cauliflower, beets, and chard do best on a high-lime soil. Onions and leeks are very sensitive to a lime deficiency. Watermelons are injured by liming, except when the soil is extremely acid, and potato scab is more difficult to control on limed soils. In general, however, for the successful production of the vegetable crops, on acid soils lime is essential, but care should be taken not to overlime.

**E. Cereals and grass crops.** The cereals and grass crops may well be considered heavy feeders on all three of the fertilizer constituents. As a group, the cereals are soil-exhausting crops.

The small grains do not deplete soils so rapidly as do tilled grain crops, such as corn. Land in small grains is less subject to erosion than land in rowed crops. So long as land is kept in grass and a good sod maintained, the soil will be conserved from the standpoint of fertility and erosion. However, in order to maintain a good grass sod, it is necessary on most soils to apply plant food as fertilizer or manure, and frequently to use lime also.

Both cereal and grass crops require considerable amounts of nitrogen. For the development of grain, adequate phosphorus is required. Potash is also used in relatively large amounts; and on potash-deficient soils or where the crops are sold from the farm, it must be supplied in the fertilizer. The removal of cornstalks, straw, and hay from the farm increases the need for potash. In small grain, excess nitrogen will cause lodging of the plants.

The cereal and grass crops do not respond especially well to lime. In farm practice, they are benefited most by liming when the lime is used for the clover or alfalfa, enabling these legumes to utilize more atmospheric nitrogen and increase the available nitrogen supply of the soil, which in turn benefits the grass and grain crops. Some grasses, like redtop, bent grass, carpet grass, and fescue, grow luxuriantly on lime-deficient soil. Kentucky bluegrass, on the contrary, requires soil high in lime, or at least not extremely acid.

**F. Tree fruits.** The tree fruits have deep and extensively developed root systems. They are able to utilize the mineral plant-food of the soil advantageously. It is only where there is a marked shortage or an unusually low availability of phosphoric acid and potash, in both surface soil and subsoil, that the trees respond to these minerals. Lime is seldom directly beneficial to the tree fruits, and it is known to be injurious to the citrus fruits.

Orchards, in general, have responded best to nitrogenous fertilizers. This has been found true for both tree growth and fruit production. Their successful fertilization becomes largely a question of supplying the nitrogen need in the most economical way, which may necessitate using other plant-food in the fertilization of orchard cover crops.

**G. Bush and vine fruits.** In general, the small fruits are less efficient than tree fruits in utilizing the mineral plant-foods of the soil. In composition they are not dissimilar to the tree fruits. They also respond primarily to nitrogenous fertilizer, but have been found to justify the minerals—phosphoric acid and potash—in addition. The production of small fruits may be classed as a more intensive system of cropping than orcharding, affording the possibility of a greater net return to the acre, and will more often justify the use of complete fertilizer.

**H. Cotton and tobacco.** Cotton has an unusually high nitrogen requirement. The composition of the stalks and leaves indicates a nitrogen content similar to that of the legumes. With cotton, all this nitrogen must be furnished by the soil. While the lint contains relatively little nitrogen, phosphoric acid, or potash, it is produced in association with the seed, which requires relatively large amounts of both nitrogen and phosphoric acid. Many of the soils of the Cotton Belt are sandy in character and not abundantly supplied with potash, and because of the coarse texture and low organic-matter content of the soil, what potash there is does not become available rapidly. For these various reasons, the successful production of cotton generally requires the use of a complete fertilizer.

TABLE VII

COMPOSITION OF CROP AND ANIMAL PRODUCTS AND BY-PRODUCTS OF THE FARM

(Average Pounds per Ton)

| Product | Nitrogen | Phosphoric Acid | Potash |
|---|---|---|---|
| Apple pomace | 4.1 | 0.05 | 3.5 |
| Barley straw | 11.9 | 4.0 | 22.0 |
| Butter | 2.9 | 1.0 | 0.6 |
| Corn cobs | 7.8 | 1.2 | 9.0 |
| Corn stover | 14.8 | 8.0 | 18.0 |
| Cotton seed | 62.0 | 25.0 | 23.0 |
| Cotton stalks | 49.2 | 20.5 | 35.0 |
| Eggs | 44.2 | 8.0 | 3.0 |
| Fat cattle | 49.2 | 32.4 | 2.4 |
| Hogs | 35.4 | 13.8 | 2.4 |
| Milk | 9.8 | 4.0 | 3.6 |
| Oat straw | 11.8 | 4.0 | 25.0 |
| Rye straw | 9.8 | 6.0 | 17.0 |
| Wheat straw | 9.8 | 3.0 | 12.0 |

Tobacco contains an unusually large amount of potash; in fact, the stems are themselves used as a potash fertilizer. Potash has been found to be a most important constituent of tobacco fertilizers. Nitrogen occurs in relatively large amounts, but the phosphoric acid content of tobacco is exceedingly low. However, in determining the composition of the fertilizer to use for tobacco, adjust the amount of nitrogen to the type of tobacco grown and to its effect on the quality of the crop. The phosphoric-acid content of tobacco fertilizers should often be higher than crop composition would indicate was needed.

**I. Composition of farm products.** In addition to the requirements of crops as indicated by their composition, it is of interest to note the composition of certain crop and animal products of the farm. Table VII gives the information on the basis of a ton of material. These figures will be found of value in making calculations relative to the gain or loss of plant-food through different cropping and farming systems.

## COMMUNITY STUDIES

1. Visit one or more of the better farms of the community where good crop yields are being secured.
2. Secure information as to the rotation or rotations followed, quality of seed used, and means employed for the control of plant diseases and insect pests; also the tillage, lime, manure, and fertilizer practices followed.
3. Determine, as far as possible, the reasons for the good crop yields.
4. List any special field crops other than those grown regularly in rotations. How are these special crops fertilized?

## PROBLEMS

1. Estimate the average annual yield of each of the common field crops of the community. Calculate the nitrogen, phosphoric acid, and potash required to the acre by each of these crops. (Refer to Table VI.)
2. Calculate the number of pounds of water that would be required for a 4-ton yield of alfalfa hay containing 10 per cent water. (Refer to Table V.)

3. A farmer sells annually the following livestock and produce: Thirty 1000-pound steers; eighty 200-pound hogs; 4 tons of eggs; 4000 pounds of butter; and a thousand 100-pound cans of milk. Calculate the pounds of nitrogen, phosphoric acid, and potash he sells from the farm annually. (Refer to Table VII.)

4. The surface soil from a Pennsylvania limestone valley would supply phosphoric acid for how many 75-bushel corn crops? Potash for how many such crops?

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## CHAPTER III

## CONTROLLING THE WATER SUPPLY OF THE SOIL

Crop yields are dependent on an adequate water supply. In dry seasons, the controlling factor of yields may be an insufficient amount of water; in wet seasons, where soils are inadequately drained, an excess of water may cause serious injury to crops. Soils themselves are frequently injured during periods of heavy rainfall by surface washing or erosion. Irrespective of climatic conditions, the successful production of crops necessitates a certain degree of control of the water supply of the soil.[1]

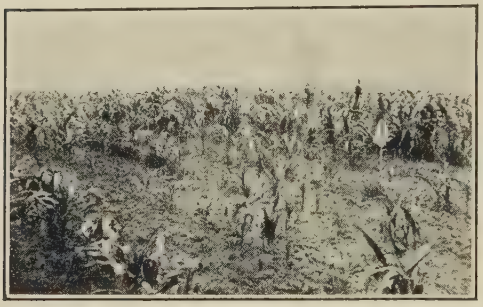

FIG. 43. CORN INJURED BY INADEQUATE DRAINAGE. (Agronomy Dept., N. Y. State Col. of Agr.)

In wet seasons, where soils are inadequately drained, an excess of water may cause serious injury to crops.

In humid sections, with an annual rainfall of 30 inches or more, and a satisfactory proportion of it during the growing season, yields are not primarily dependent on the water supply. Where soils have a poor water-holding capacity, and especially where the transpiration and evaporation are high, additional water will be needed. Of relatively greater importance in humid sections are the draining of wet soils and the control of erosion where soils are subject to washing. However, in the semi-arid regions of the West, it is necessary to conserve the water supply and to utilize it economically by means of a special system of soil and crop management called *dry-land farming*. In the arid sections, water must be applied artificially by means of irrigation.

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[1] See General Information at end of chapter for explanation of functions of different forms of soil water; also see page 31.

**Operations:**

1. Determining the feasibility of drainage.
2. Laying out the drainage system.
3. Digging the ditch to grade.
4. Installing the tile.
5. Caring for the drainage system.
6. Irrigating land.
7. Practicing dry-land farming.
8. Controlling soil erosion.

### 1. Determining the Feasibility of Drainage

Some undrained soils are of such a nature that even if drained they would have little agricultural value. Others are so situated that an adequate fall cannot be secured, and not infrequently the cost of installing an adequate drainage system is prohibitive. Obviously, then, before draining land one should determine the practicability of the operation.[2]

**Procedure:**

A. Examine the soil.
B. Make certain of an adequate fall.
C. Estimate the cost.

**A. Examine the soil.** A thorough inspection of the soil should be made first. Determine the character and depth of the surface soil and subsoil, making certain that with drainage the land is suited to crop production. Examine the subsoil from the standpoint of its fitness not only for crop production but also for drainage. An impervious layer in the subsoil within 3 feet of the surface makes artificial drainage more difficult and less effective.[3] Where a sizable area is under consideration and there is some doubt as to the agricultural value of the land when drained, secure the services of a soil expert. Be very sure that the soil is worth draining before proceeding.

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[2] See General Information at end of chapter for benefits of drainage.

**B. Make certain of an adequate fall.** A drainage system must have a sufficient fall. Seeps along hillsides and low, wet areas along inadequately formed drainage ways will normally offer sufficient fall and a satisfactory outlet for artificial drainage. However, where the land is level without natural drainage ways, it is necessary to make certain of an adequate outlet and of the possibility of securing a sufficient fall between all parts of the area and the outlet. This may necessitate the use of a land level. With this instrument, determine

FIG. 44. DETERMINING THE FEASIBILITY OF DRAINAGE. (Agronomy Dept., N. Y. State Col. of Agr.)

Where the land is level without natural drainage ways, it is necessary to make certain of an adequate outlet and of the possibility of securing a sufficient fall between all parts of the area and the outlet.

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[3] See page 29 for discussion of surface soil and subsoil.

the elevation of the lower spots in the area to be drained in their relation to that of the outlet.[4] Measure the distance between the outlet and these low areas, and calculate the available fall. It is desirable to have a fall of 3 inches to 100 feet, though 2 inches or even less will suffice for laterals. To provide the desired 3-inch fall, the elevation of an area located 1000 feet from the outlet should be 30 inches greater than that of the ground level at the outlet. In an emergency, 10 inches to a foot of this fall may be secured by adjusting the depth of tile. Unless certain of an adequate fall, secure the services of a drainage engineer.

**C. Estimate the cost.** Before proceeding with a drainage project, make a rough estimate of the cost. An accurate calculation of the total outlay cannot be made until the plan is fully worked out in its various details, but a rough estimate can be made on the basis of local cost of labor and tile. Here, again, the judgment of a drainage expert will be of value. Good soil will justify almost any reasonable expenditure for drainage. This is particularly true where the poorly drained areas interfere with the economic management of fields that are otherwise well drained, and where the soil is to be used for the production of vegetables or other high-value crops.

Briefly stated, the conditions justifying artificial drainage are as follows:

(1) Land, otherwise good, that has a low agricultural value because of inadequate drainage.

(2) Soil that is so wet and cold in the spring that seed-bed preparation is hindered and seeding seriously delayed.

(3) Soil that does not dry quickly enough after rains to permit adequate cultivation of the growing crop.

(4) Crop injury due to excess water in wet seasons, or to drought in the late summer or early fall, as a result of a

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[4] For directions for leveling, see Chapter VI of "Farm Engineering," Vol. I, by B. B. Robb and F. G. Behrends, published by John Wiley & Sons.

shallow root system caused by poor drainage earlier in the season.

(5) Small wet areas in a field that is otherwise well drained.

### 2. Laying Out the Drainage System

In the Corn Belt many farms have complete drainage systems installed. On the uplands in the eastern and southern states, artificial drainage has been confined largely to wet spots in fields or to relatively small areas of the farm. The utilization of bottomlands and old lake beds, including muck and peat deposits, irrespective of location, has often necessitated the installation of complete drainage systems. The type as well as the extent of the drainage system will depend on the local conditions.

**Procedure:**

A. Plan the whole system.
B. Locate the outlet.
C. Determine the fall.
D. Decide on the type of drainage system.
E. Locate the position of mains and laterals.
F. Determine the size and quantity of tile needed.

**A. Plan the whole system.** Before starting actual drainage operations, work out a plan for the whole farm, at least for a part having a single drainage outlet. Unfortunately, farmers frequently install small drainage units which cannot be fitted into the complete drainage system which they may ultimately find desirable. Plan the whole system even though only a small unit is to be established in the beginning. After a definite plan has once been developed, it can be executed in small units, as the time, capital, and other facilities justify.

In the planning of the drainage system, secure advice from your college of agriculture, either directly or through the local county agricultural agent. In addition to determining the feasibility of drainage, the extension specialist in drainage can give valuable suggestions, and possibly render personal assistance in planning the details of a drainage system for the individual farm.

**B. Locate the outlet.** In the development of the plan, the first point to decide is the location of the outlet or outlets of the system. This, of course, has been tentatively determined in the original survey conducted to make certain of an adequate fall, but even so, it should now be done more carefully since it constitutes a most important part of the drainage plan. The outlet should normally be located at the lowest

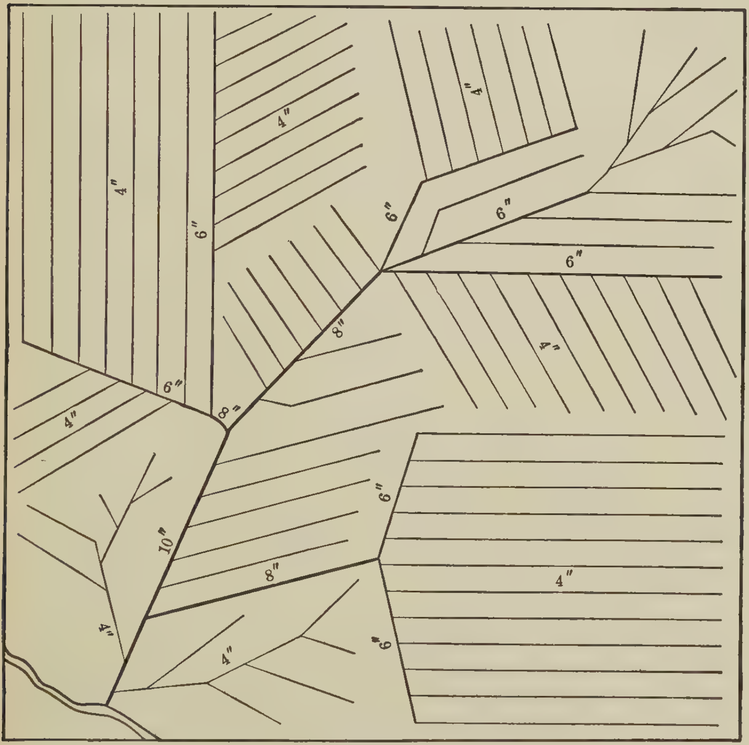

FIG. 45. A FARM DRAINAGE SYSTEM.

Before starting actual drainage operations, work out a plan for the whole farm.

surface level along the stream or ditch into which the drainage water is to be discharged. The position finally chosen should lend itself to adequate protection where a tile system is to be installed. Locate it above the normal water level in the ditch or stream, for otherwise water will back up into the drains, permitting silt to accumulate and clog them. At times of freshets, water may possibly back up into the drains without causing permanent injury.

**C. Determine the fall.** The fall from the various areas requiring drainage to the outlet must now be determined more accurately. This will normally require the use of a land level. Except where the drainage operation requires only the simplest kind of plan, prepare a contour map of the area which is to be drained. Such a map indicates by so-called contour lines the topography or the variation in the surface elevation of the area. With it, the amount of fall available between any two points can readily be calculated.

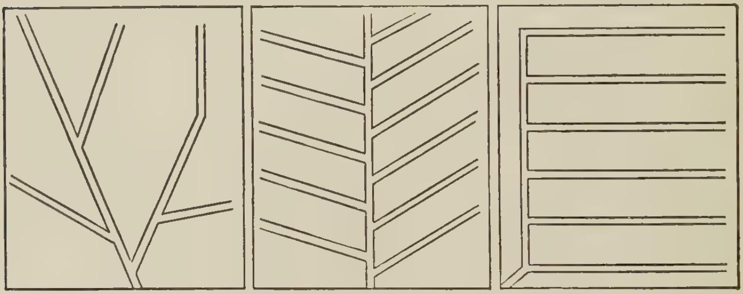

FIG. 46. TYPES OF TILE DRAINAGE SYSTEMS.

There are three types of drainage systems: (1) natural, (2) herringbone, and (3) gridiron.

**D. Decide on the type of drainage system.** With the available outlets located and definite information secured relative to the fall between the outlets and the areas to be drained, the type of drainage system best suited to the conditions can be determined.

There are three main types of tile systems: (1) *natural,* (2) *herringbone,* and (3) *gridiron* (see Fig. 46). The natural type is best suited to the draining of flat areas at the headwaters of streams. It is the type commonly used for draining hillside seeps and small wet spots in rolling fields. The gridiron and herringbone types are best suited to relatively level land where drainage is needed uniformly over a considerable area. All three types consist of a main and numerous laterals. It may be found desirable to utilize two types, or even all three, in draining a single farm.

Tile, under most conditions, has been found superior both in efficiency and permanency to other types of drains, but there are at least four conditions under which open ditches should be used:

(1) In draining muck and peat, where the soil may settle to such an extent as to destroy the true grade of the tile system, thus rendering it inoperative.

(2) Where the volume of water is large, either permanently or for short periods during heavy rainfall.

(3) Where land is so near water level that tile cannot be installed below the frost line.

(4) Where the soil is of low value, or the area is to be used for a low-value sod crop such as hay or pasture, and only moderate improvement in drainage is necessary.

Although stone and log drains have been installed to some extent, they are inferior to tile and cannot be recommended as either permanent or efficient.

Choose the type of drainage system best suited to the conditions on the individual farm. If tile drainage is to be installed, select the system or systems best adapted to the field that is to be drained.

**E. Locate the position of mains and laterals.** In locating the main, start at the outlet and work back conforming as far as possible to the natural topography, and at the same time maintaining a generally straight course. Any necessary turns in the main tile should be in the form of broad curves. Avoid sharp turns. The laterals should enter the main at an acute angle, with the flow in the same direction as that in the main. The distance between laterals will depend on the character of the soil, and the depth to which the tile is to be laid. The deeper the tile is placed in the ground the wider will be the strip drained. This is illustrated in Fig. 47. In a clay soil with tile 24 to 30 inches deep, the laterals should not be over 32 feet and preferably 24 to 28 feet apart.[5] In friable loams with the tile installed to a depth of 30 to 40 inches, 40 to 60 feet should be allowed between laterals; in light, sandy loams with tile 40 to 48 inches deep, this distance may be increased to 80 or even 100 feet.

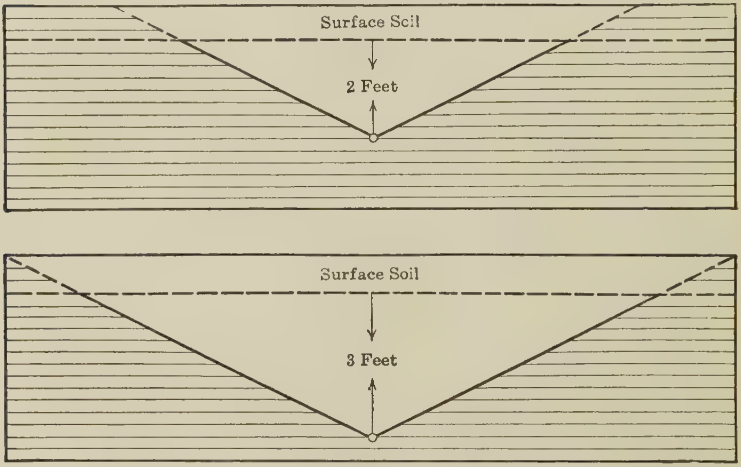

Fig. 47. Relation of Depth to Distance between Tile.

The deeper the tile is placed in the ground the wider will be the strip drained.

**F. Determine the size and quantity of tile needed.** Round tile are now used almost exclusively. The main should be of adequate size to handle the water efficiently from all laterals of the completed systems when they are delivering their maximum flow. This will depend primarily on the size of the area drained, the amount of rainfall, and the grade of the main. It will be influenced also by the character of the soil, the distribution of the rainfall, and the crop on the land. With a 4- to 5-inch fall and an annual precipitation of 36 inches, a 6-inch main would handle the water from 20 to 30 acres; an 8-inch would suffice for an area of 40 acres; and a 10-inch, for 60 acres. The size of tile refers to the inside diameter in inches. Select the proper size for the main on this basis, and use either 3- or 4-inch tile for the laterals. Seldom will

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[5] See Chapter I for soil classification.

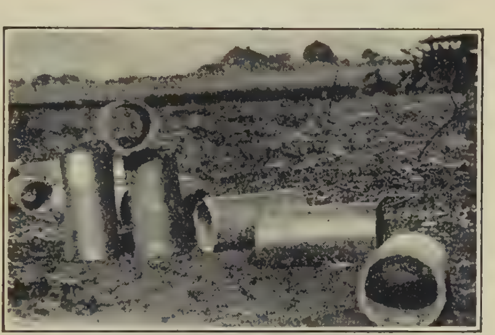

Fig. 48. Round Tile.

Round tile are now used almost exclusively.

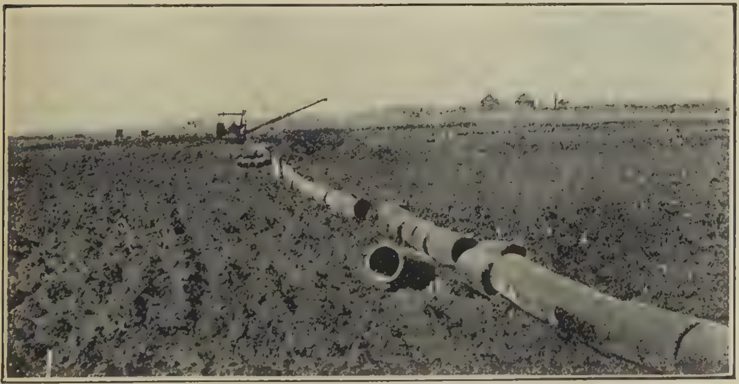

Fig. 49. A Ten-Inch Main.

The main should be of adequate size to handle efficiently the water from all laterals of the completed system when they are delivering their maximum flow.

a 5-inch be required, and anything smaller than a 3-inch tile is impractical.

Drainage tile is commonly made in standard 12-inch lengths. With the plan of the tile system completed, including the size of tile to be used in mains and laterals, the number of tile of each size needed can readily be calculated. A few extra tile should be ordered, to allow for breakage and to permit the discarding of any that are imperfect or of poor quality. One may purchase junction tile of the diameter of the main with connections of proper size for standard 3- and 4-inch laterals. It is advisable to include the necessary V-shaped junction sections in the tile order, even though, with care, tile can be chipped so as to make a satisfactory connection between the main and the laterals.

### 3. Digging the Ditch to Grade

Before starting to dig the ditch, the grade should be carefully worked out and the required depth of ditch calculated for various points along the drainage course.

**Procedure:**

A. Determine the depth of ditch.
B. Dig the ditch.
C. Scrape to uniform grade.

**A. Determine the depth of ditch.** The depth to which the tile should be laid for greatest efficiency will vary with conditions. Water enters the tile largely from the bottom. It is when the water table rises to the height of the tile that the gravitational, or free, water enters through the joints between the tile. For most crops it is desirable to have the water table at least 30 inches below the surface. Install the tile to an average depth of between 30 and 36 inches. Have the tile at least 24 inches deep even at the upper end, and not more than 4 feet at the outlet.

Having determined the available fall for the drainage system and the depth of the tile at the outlet, proceed as follows to determine the depth of ditch at other points. Starting at the outlet, drive a stake firmly into the ground about 2 feet to the side of the center line of the ditch. This stake should be driven so that the top is within an inch of the ground level. This is called a *hub stake.* In order that it may be readily located, drive another stake lightly into the ground nearby. This second stake is called a *witness stake.* Working back from the outlet, drive additional hub and witness stakes at regular intervals, preferably of 50 feet, though some use 100 feet, along the side of the proposed ditch line for mains and laterals.

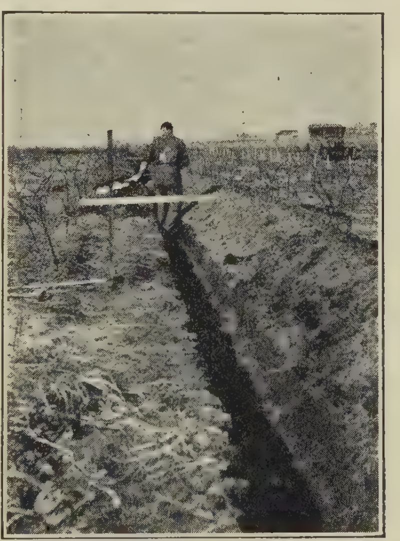

Fig. 50. Digging the Ditch by Hand.

Hand digging has been found practical for small to moderately sized areas.

By the use of the land level, determine the relative elevation of the various hub stakes. With this information in addition to the known available fall for the whole drainage system, the necessary depth of ditch at each hub stake can be figured out in the following manner.

First add the depth of the outlet to the level reading of the hub stake at the outlet. Then subtract from this figure the amount of fall to the hundred feet,[6] and from the result obtained subtract the level reading at the first hub stake above the outlet. This gives the depth to which the ditch must be dug at this hub stake. To calculate the depth of the ditch at successive hub stakes, proceed as before, multiplying the amount of fall to the hundred feet by the number of 100 feet at which the hub stake is located above the outlet. When calculated mark on each witness stake the depth to which the ditch is to be dug at each corresponding hub stake. If hub stakes are 50 feet apart use one-half the fall for 100 feet in making calculations.

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[6] See General Information at end of chapter for illustration of method of calculating depth of ditch.

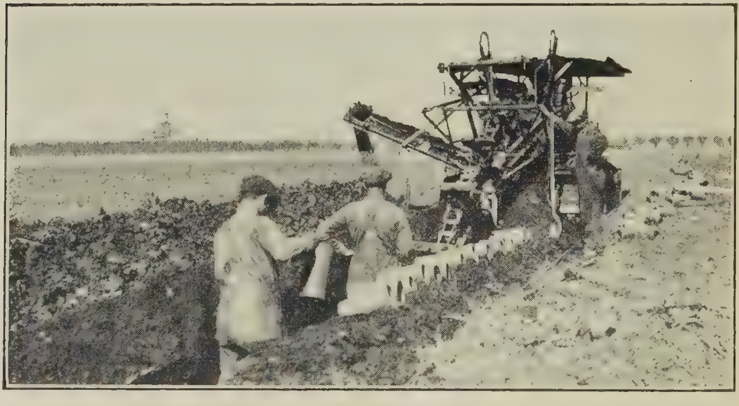

Fig. 51. Power Ditcher at Work.

The power ditcher, if available, can be utilized advantageously in excavating for extensive drainage systems.

**B. Dig the ditch.** In digging the ditch, start at the outlet. Use a drainage spade. In stony or gravelly soil a pickax can be used to advantage. The ditch should be from 12 to 15 inches wide, depending on the depth; the deeper the ditch the wider it should be. Because of the larger-sized tile as well as the greater average depth, dig the main ditch somewhat wider than the laterals. Maintain as far as possible a uniform width from top to bottom, and throw the excavated soil far enough to one side to prevent it from working back into the ditch.

Hand digging has been found practical for small to moderate-sized areas. The power ditcher, if available, can be utilized advantageously in excavating for extensive drainage systems.

In digging the ditch, exercise care not to dig below the final grade level. Check on the depth at each hub stake as recorded on the witness stake, and estimate from the surface topography the approximate depth between stakes. Use care not to dig deeper than the finished ditch bottom. If the ditch is dug below final grade level, it will be necessary to fill in and tamp the soil down firmly before the tile can be laid.

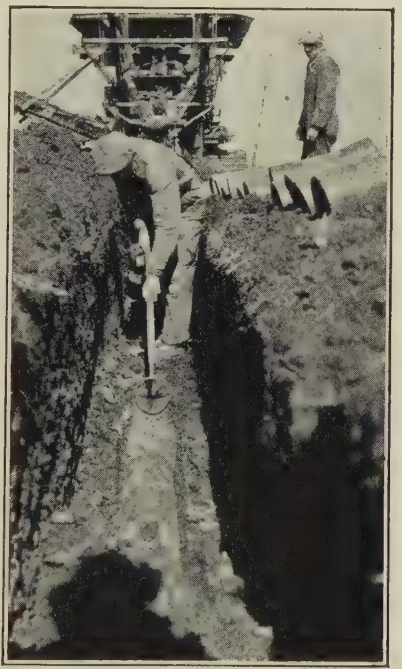

FIG. 52. PREPARING THE DITCH BOTTOM.

A drainage scoop can be used advantageously in preparing the bottom of the ditch for the tile.

**C. Scrape to uniform grade.** After the ditch is dug, the bottom must be worked down to the required grade. This can be done accurately by reproducing the grade, with a heavy cord stretched taut 5 feet above the final ditch bottom. A supply of 2- by 3-inch stakes about 4 feet long, and half as many 1- by 3-inch wood strips, also 4 feet long, will be needed for this purpose.

Starting at the outlet, drive a stake alongside the hub stake, being careful not to disturb the level of the latter. Drive another stake across the ditch at a distance of about

3½ feet. Subtract from 5 feet the depth of the ditch as indicated by the figure on the witness stake. The result is the height the string should be above the hub stake. From the top of the hub stake, measure this distance on the adjoining stake and mark with pencil. Now fit one end of a wooden strip to the stake so that the top will be flush with the pencil mark. Nail in position. Level the strip and nail the other end securely to the stake on the opposite side of the ditch. In the same way erect cross strips over the ditch at exactly 5 feet above grade bottom at each hub stake. Starting at the outlet, stretch a string over the cross pieces for a distance of at least several hundred feet. Have this string taut. The string can be changed as the ditch bottom is finished.

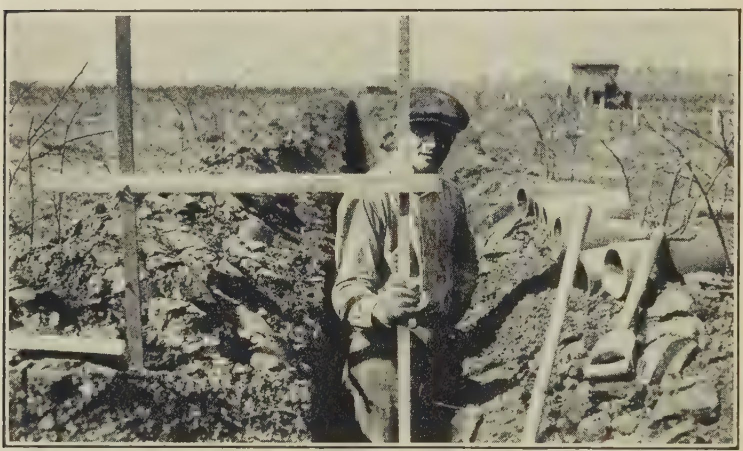

FIG. 53. CHECKING THE DEPTH OF THE DITCH.

By means of a 5-foot gauge stick, check the ditch bottom with the grade string above.

Starting again at the outlet, prepare the bottom of the ditch for the tile. Work it down to exact grade level. A drainage scoop can be used advantageously for this purpose. It produces a groove into which the tile fits nicely. By means of a 5-foot gauge stick, check the ditch bottom with the grade string above, keeping the string taut so that it will not sag between supports.

## 4. Installing the Tile

As the ditch bottom is completed, haul the tile to the field and distribute along the line of the ditch. This completes the necessary preparation for the installation of the tile.

**Procedure:**

A. Lay the tile.
B. Fill the ditch.
C. Protect the outlet.

**A. Lay the tile.** Put the tile in place either by hand from within the ditch or with the aid of a tile hook from without. Start at the lower or outlet end. Adjust each piece so that it fits snugly into the adjoining piece. The individual pieces vary in shape so that by turning, and where necessary reversing end for end, a tight joint can be secured. At best there will be a sufficient opening for the water to enter, and unless care is exercised in the laying, the joints may be so open that silt will enter and clog the tile. Adjust the tile so that any opening of more than 1/8 inch comes at the bottom. If a satisfactory adjustment cannot be made, cover the opening with a curved piece of tile. In laying around

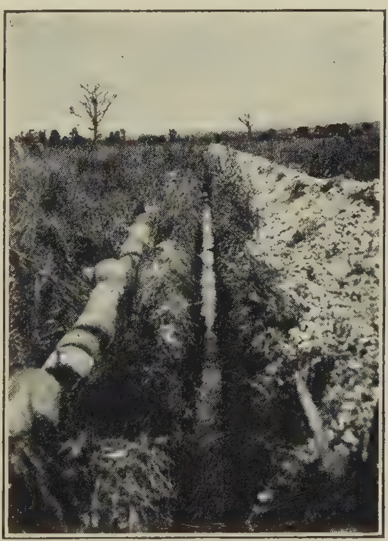

Fig. 54. Tile Distributed along the Ditch.

As the bottom is completed, haul the tile to the field, and distribute along the line of the ditch.

curves, select tile that have somewhat beveled edges, or are slightly curved. By picking the tile in this way, satisfactory joints can generally be secured. Where sharp curves have not been avoided, it may become necessary to chip the edges to secure a snug fit. Place a board, flat stone, or a little concrete over the opening at the upper end of each line of tile so that soil cannot wash in and burrowing animals cannot enter.

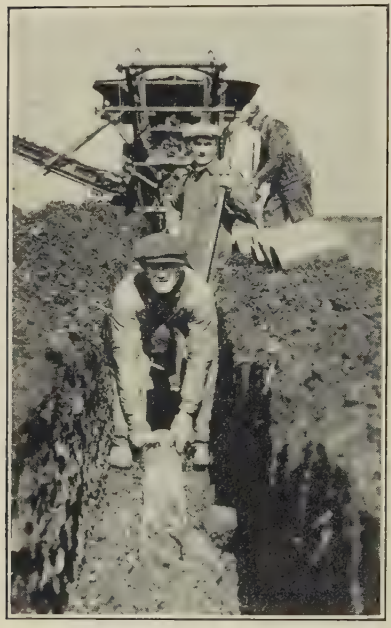

FIG. 55. LAYING THE TILE.

Put the tile in place either by hand from within the ditch or with the aid of a tile hook from without. Adjust each piece so that it fits snugly into the adjoining piece.

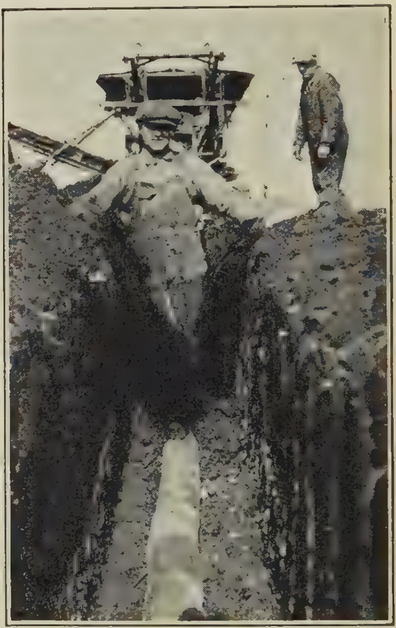

FIG. 56. BLINDING THE TILE.

As the tile is laid, an inch or two of surface soil should be thrown into the ditch to hold it in place. This operation is called *blinding the tile.*

Any defective tile should be discarded. They can be broken and the pieces used to cover open joints. A tile system may become inoperative as a result of the breaking of a single soft tile. The permanency, as well as the efficiency of operation, is dependent in no small degree on the exactness with which the tile is laid.

**B. Fill the ditch.** As the tile is laid, an inch or two of surface soil should be thrown into the ditch to hold it in place. This operation is called *blinding the tile.* Care should be taken not to disturb the position of the tile as the soil is distributed about it. If the tile is blinded daily as laid, it will be protected so that even a heavy rain will not disturb it. It is especially desirable to use surface soil for blinding if the subsoil is of a heavy clay character, as the more porous surface material will facilitate the entrance of the water into the tile and thereby increase its efficiency.

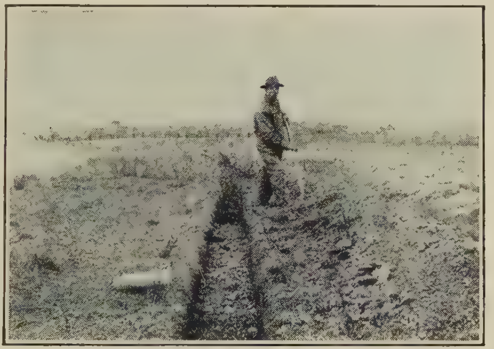

Fig. 57. Filling the Ditch. (Agronomy Dept., N. Y. State Col. of Agr.)

Complete the filling of the ditch when convenient. Often a plow or a scraper can be used to advantage in replacing the excavated soil.

Complete the filling of the ditch when convenient. Often a plow or a scraper can be used to advantage in replacing the excavated soil. At least part of it will have to be shoveled back by hand. When possible, fill the ditch promptly before the excavated soil becomes compact.

**C. Protect the outlet.** The outlet should now be permanently constructed. Protect it against possible displacement of the end tile by erosion or by the tramping of farm animals. This protection can be furnished by the proper use of stones where they are available. Concrete often can be employed to advantage. Judgment must be used in determining the type of construction. It is well to protect the end of the last tile with vertical iron bars placed about 2 inches apart. This also prevents the entrance of animals.[7]

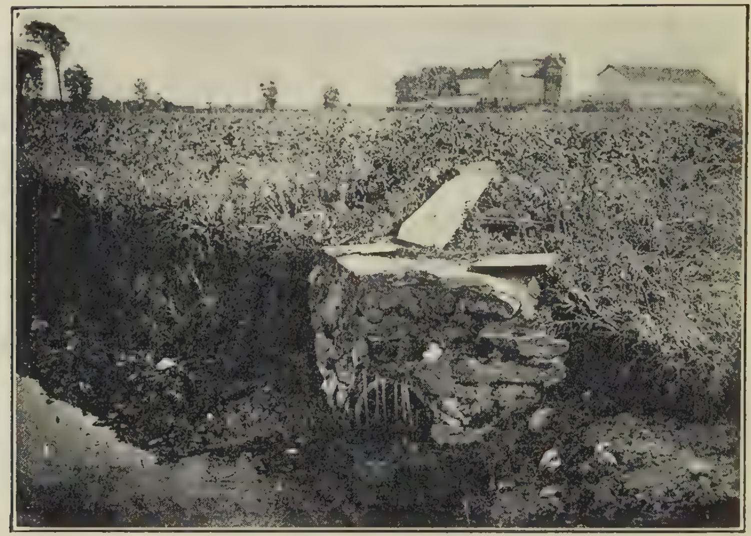

FIG. 58. A WELL-PROTECTED OUTLET. (Agronomy Dept., N. Y. State Col. of Agr.)

Protect the outlet against possible displacement of the end tile by erosion or the tramping of farm animals.

### 5. CARING FOR THE DRAINAGE SYSTEM.

Although a properly constructed drainage system should be permanent in character, some attention must be given to inspection and repair to keep it functioning effectively.

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[7] For more detailed information on installing tile drainage systems see "Farm Engineering," by Robb and Behrends, published by John Wiley & Sons.

**Procedure:**

A. Inspect regularly.
B. Clean open ditches.
C. Repair breaks or stoppages in tile.
D. Keep the outlet in good repair.

**A. Inspect regularly.** Any type of drainage should receive regular inspection. Watch open ditches and determine when they need cleaning. Check on the flow from the tile system, making certain that it is functioning properly. Watch for the development of wet spots along the line of tile because they indicate stoppage in the system and the need of immediate repair.

**B. Clean open ditches.** Open ditches will need occasional cleaning. Do this work in the late summer or early fall, or in the southern states, during the winter months. In addition to keeping the ditches themselves clean, cut the weeds and brush from the edges.

**C. Repair breaks or stoppages in tile.** Repair promptly any stoppages which develop in a tile system. Breaks can generally be located by the development of a wet spot over the line of tile. Where such develop, dig out the ditch and replace any broken tile. Remove and clean any tile in the vicinity of the stoppage that have become partly filled. Where the clogging has been caused by a broken tile, the new tile can be relaid on the original grade. In this event care should be taken in removing clogged tile not to disturb the level of the ditch bottom. Where stoppage is caused by a sag in the line of tile, it will be necessary to fill in the ditch to correct grade before replacing the tile removed.

**D. Keep the outlet in good repair.** Where the outlet is well constructed, it should need little attention. Nevertheless, it should be inspected occasionally to make certain that it is not in need of repair or cleaning. Where repair is needed, attend to it promptly as a neglected outlet may render the whole system inoperative.

### 6. Irrigating Land

Irrigation is practiced most extensively in sections having an annual rainfall of less than 15 inches. (See Fig. 66.) Such areas of extremely low rainfall are confined largely to the western third of the United States. Irrigation is also practiced in certain of the southern states in connection with rice production. In some sections having a relatively high annual rainfall, there are seasonal periods of very dry weather. In Florida, for example, the winter months are dry, while in the Pacific northwest the summers are dry. Irrigation is practiced to some extent in both sections during the dry periods.

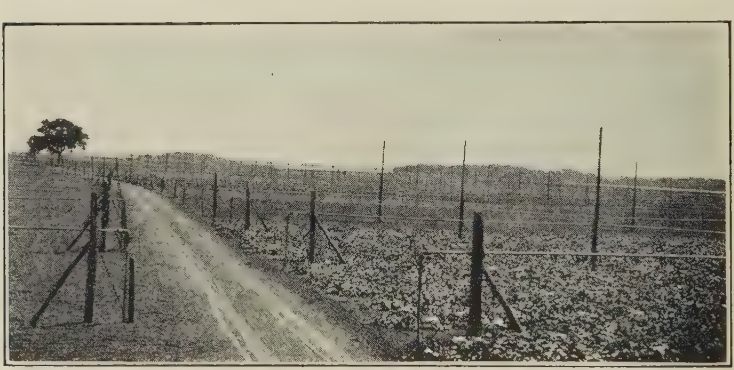

Fig. 59. Overhead Sprinkler System of Irrigation.

In the eastern states, overhead artificial watering systems, a type of irrigation, are used to some extent in intensive vegetable production.

Overhead watering systems, a type of irrigation, are used in various sections to some extent in intensive vegetable production. However, the large irrigation projects of the country are found in the arid and semi-arid sections which are confined to the western and southwestern states.

**Procedure:**

A. Make certain of a satisfactory water supply.
B. Prepare the field to receive the water.

C. Apply the water.
D. Cultivate when the surface dries.
E. Prevent alkali injury.

**A. Make certain of a satisfactory water supply.** A dependable water supply is essential for successful irrigation farming. In some instances well water is used for irrigation, but in the arid sections, impounded surface water is used. The source of supply is often a great distance from the area irrigated.

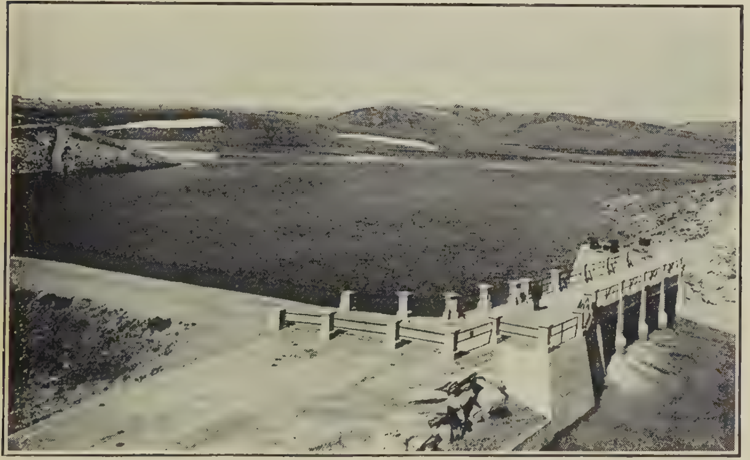

FIG. 60. IRRIGATION DAM AND RESERVOIR.

The development of the larger irrigation projects has entailed enormous expenditures for the construction of dams and reservoirs for the collection and storage of water.

Not only should water be available at all seasons, but it also should be secured at a reasonable price. Frequently the stream water in arid sections carries a sufficient amount of undesirable salts to cause crop injury when applied to fields. Consequently the quality of the water is also of importance.

The development of the larger irrigation projects has entailed enormous expenditures for the construction of dams and reservoirs for the collection and storage of water, as well as for the canals and ditches necessary for its transportation to the area irrigated. The federal government has financed many of these irrigation projects. The quantity and quality of the water supply, as well as the agricultural value of the land to be irrigated, are, or should be, ascertained before the project is started. Even though precaution is used by those interested in the development of the irrigation project, care must be exercised in the purchase of irrigated land to make certain that the soil is of good quality, that alkali can be controlled, and that there is an adequate supply of good water available at a reasonable cost.

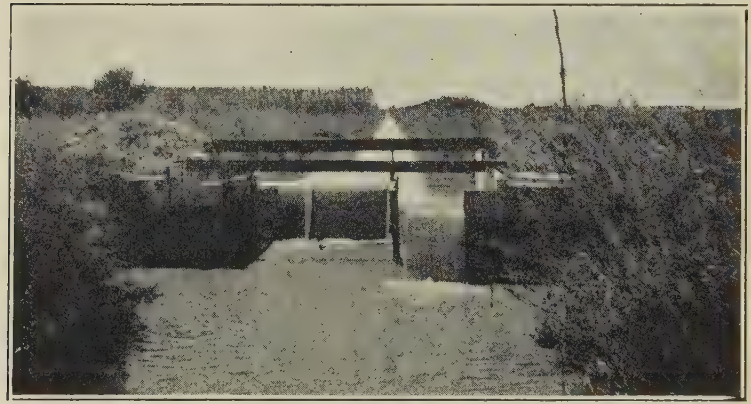

Fig. 61. Irrigation Ditch.

The water is conducted from the main irrigation ditch to the various fields of the farm by means of smaller open ditches.

**B. Prepare the field to receive the water.** The water is conducted from the main irrigation ditch to the various fields of the farm by means of smaller open ditches. These should have a uniform fall and be maintained in good condition. The water is distributed over the field by one of two methods. For alfalfa, small grain, and other crops that fully occupy the ground, the field is covered uniformly with several inches of water. This method of irrigation is called *flooding.* For field crops grown in rows and for orchards, the water is commonly distributed in furrows or ditches. This method is known as *furrow irrigation.*

There are several types of "flooding." It is seldom that the field as a whole is level enough to permit of its being flooded as a unit. The *border method* consists in dividing the field into strips separated by low ridges. These strips follow the topography, and provision is made to supply water at the upper end so that it will run down more or less uniformly, covering the surface of the whole strip. The *check method* consists in separating the field into smaller square or rectangular areas by the construction of ridges or low dikes. When this method is used in orchards, it may be referred to as the *basin type* of irrigation.

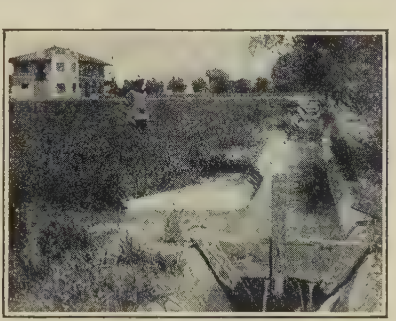

Fig. 62. Flooding Alfalfa Field. (Agronomy Dept., Ill. Agr. Exp. Sta.)

For alfalfa, small grain, and other crops which fully occupy the ground, the field is covered uniformly with several inches of water.

Where the flooding method, or a modification of it, is to be used, level the field properly so that the water will cover all parts to a uniform depth. Around each area construct low ridges of sufficient height to prevent the passage of water from one area to another. After a field has once been prepared properly, it requires very little attention to keep it in condition for future flooding.

In preparing the land for furrow irrigation, use a plow for opening up the furrows. Unless a good clean furrow is produced, use a spade or shovel to finish it. Locate the furrows so that they will be absolutely level, or will have a very gradual but uniform fall from the irrigation ditch to the opposite end. The distance between furrows should vary with the character of soil and the kind of crop grown, but it should normally be from 6 to 10 feet.

**C. Apply the water.** The time and frequency of applying the water, as well as the amount to apply at a time, depend on such factors as the character of the soil, kind of crop, rainfall, and supply of water available.

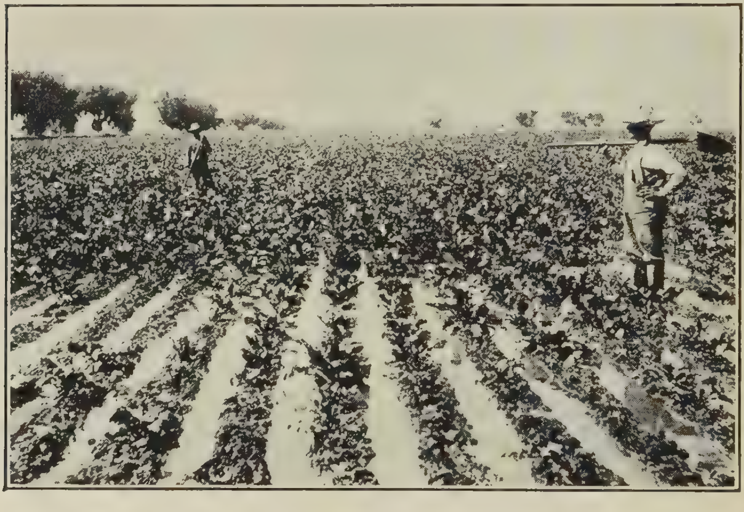

Fig. 63. Furrow Irrigation. (Agronomy Dept., Ill. Agr. Exp. Sta.)

For field crops grown in rows and for orchards, the water is commonly distributed in furrows or ditches.

Under most conditions enough water should be applied at a time to satisfy the water-holding capacity of the soil to a depth of several feet. Where alkali control is a factor, some excess water may be justified provided there is satisfactory underdrainage, in order that the soluble-salt content of the upper soil may be maintained at a point low enough to prevent crop injury. In general, one can figure on an annual requirement of 1 or 2 feet of water.

In irrigating most annual crops, apply water at least twice during the growing season. Wheat and other small grains often require three to five applications of water for best results, whereas alfalfa normally receives three and sometimes four waterings a season. Potatoes and some other vegetable crops respond well to light applications of about an inch of water once every week or 10 days. The frequency of applying water, as well as the amount to apply in irrigating fruit, varies greatly, though the time of applying the water is often determined by the rate of growth of the fruit itself. In fact, conditions and established practices vary so much in different sections and with different crops, that it is advisable for one taking up irrigation farming to familiarize himself with the established methods developed for the individual crops in the section in which he locates.

**D. Cultivate when the surface dries.** Where feasible cultivate just as soon after irrigation as the surface soil dries sufficiently. This will reduce evaporation and lessen the loss of the water absorbed by the soil. Weeds, which may have started as a result of irrigation, will be killed while still small. At this time, while the soil has an optimum moisture content, more effective cultivation can be done. Unless this is done promptly, evaporation of water may result in a sufficient concentration of alkali salts on or near the surface to injure the crops. Prompt stirring of the soil after each application of water is essential and should be given unless a non-tillable crop is on the field.

**E. Prevent alkali injury.** The alkali problem is confined largely to regions having an annual rainfall of less than 10 inches. When soils of dry sections are irrigated, the alkali problem is frequently intensified, for it has often been found difficult to prevent the increase of alkali salts in the surface soil or to reduce the concentration once it has taken place.[8]

The only practical means of reducing the alkali is to leach it out of the soil. To accomplish this, there must be adequate natural underdrainage or else an artificial underdrainage system must be established. Unfortunately, many of the more serious alkali deposits occur where there is inadequate underdrainage. In fact, alkali forms as the result of low rainfall combined with poor drainage. Where soils naturally contain a salt-concentration toxic to plants, it is doubtful if one is justified in attempting to use them for the production of agricultural crops. Solving the alkali problem consists, first, of preventing the accumulation of injurious amounts of alkali salts in land that is being farmed; and, second, of removing any accumulation which may develop from time to time in such land.

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[8] See General Information at end of chapter for discussion of kinds of alkali and crop injury from alkali.

Fig. 64. Alkali Injury.

The alkali problem is confined largely to regions having an annual rainfall of less than 10 inches.

The control of alkali, then, resolves itself largely into the problem of leaching out soluble salts. In addition, care must be taken in irrigation not to use water which carries salt in solution in excess of that which may easily be removed by leaching. Unfortunately, difficulty is frequently encountered in removing salt from soils even where there is good underdrainage and sufficient irrigation water available.

Sodium chloride constitutes the most common alkali salt, called *white alkali*. It is not so toxic as the so-called *black alkali*. Even though sodium chloride is readily leached its removal may result in the formation of some black alkali. Also, its removal will often result in the development of undesirable physical conditions in the soil which reduce, or even prevent, the downward movement of additional water. The soil becomes puddled and difficult to till. If the irrigation water contains gypsum, or calcium in other forms, the injury is largely prevented.

Black alkali is more toxic and more difficult to remove than white alkali. Where black alkali occurs, white alkali generally is present also. If such a condition exists, or if white alkali occurs in heavy clay soils, first leach the soil thoroughly to remove as much as possible of the white alkali. Then, when it has dried to below plow depth, apply gypsum or sulfur in amounts required to counteract the sodium carbonate. To determine the rate of application, it will be necessary to have the sodium-carbonate content ascertained by analysis. Disk the gypsum or sulfur into the soil and continue the leachings until the alkali has been reduced to the point of safety. After the removal by leaching, manure, if available at a reasonable price, should be applied.

Although alkali may be leached from soils with irrigation water if there is good underdrainage, the irrigating of land often results in an increase of alkali. This occurs as the result either of the irrigation water carrying excess soluble salts or of the upward movement of salts from the subsoil to the surface soil. This upward movement may occur where there is a higher salt content in the subsoil than in the surface soil, and where there is inadequate underdrainage.

Since alkali spots frequently develop because of leaky irrigation canals, it is important that canals be so constructed that seepage cannot take place. Much can be accomplished in alkali control by proper soil tillage. The object should be to prevent the concentration of salt in the root zone of the crops. To accomplish this, surface evaporation should be kept at a minimum. This requires the maintenance of a soil mulch by frequent tillage. In fact, efficient tillage practices to keep the salts dispersed throughout the soil and to prevent the upward movement of salts from the lower portion of the subsoil are important, even when used in addition to other methods of control.

Some crops are more tolerant to alkali than others. Alfalfa, the sorghums, and sugar beets have been found suited to alkali soils. Of the small grains, barley and oats have been found preferable to wheat. Cotton, citrus fruits, and grapes—all are fairly tolerant to alkali. In farming land subject to alkali injury, grow crops which have been found most tolerant to concentrations of soluble salts.

### 7. PRACTICING DRY-LAND FARMING

In the semi-arid regions a system of soil and crop management has been developed in which the conservation of water and its economic utilization in crop production are the prime essentials. The system is known as *dry-land farming.* It is practiced extensively in the production of grain and forage crops in the Great Plains and in other semi-arid regions of the western states. In areas of low rainfall where irrigation is impractical, the practice of the principles of the system is essential for successful production of field crops.

FIG. 65. WHEAT PRODUCED BY DRY-LAND FARMING. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Dry-land farming is practiced extensively in the production of grain and forage crops in the Great Plains and in other semi-arid regions of the western states.

Dry-land farming is practiced most extensively in sections where the annual rainfall is 12 to 20 inches. (See Fig. 66.) The practice is confined largely to the states of Montana, the

Dakotas, Nebraska, Kansas, Oklahoma, northwest Texas, and eastern Wyoming, Colorado, and New Mexico. Often the distribution of rainfall is nearly as important as the total supply. Much less rain is required if it falls largely during the growing season than if it occurs chiefly in the fall and winter months. Owing to a much lower rate of evaporation in cooler climates, crops can be grown satisfactorily without irrigation and with less rainfall in the Northwest than in the Southwest. The success of dry-land farming is also dependent on the character of the soil. Light sandy soils, often deficient in organic matter, and heavier soils having open sandy or gravelly subsoils are poorly suited to this type of farming. Loams and

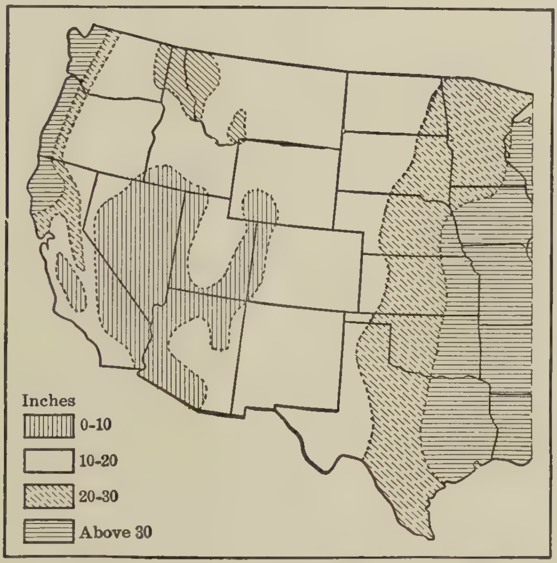

Fig. 66. Map Showing Average Annual Rainfall in the Western Part of the United States

Dry-land farming is practiced most extensively in sections where the annual rainfall is 12 to 20 inches, whereas irrigation is largely restricted to areas with a rainfall of less than 15 inches.

clay loams, well supplied with organic matter and having a heavy, uniform-textured subsoil, are capable of retaining sufficient water to be adapted to the practice of dry-land farming. Next to the supplying of adequate water, the conservation of organic matter is the most serious problem in dry-land farming.

Unfortunately, there is considerable variation from year to year in the rainfall of the region where dry-land farming is practiced. In periods of relatively high rainfall the method, when conscientiously followed, results in fairly satisfactory yields; but with a series of years of abnormally low rainfall, sufficient water cannot be made available for crop needs. During such periods serious wind erosion may develop, resulting in disastrous dust storms. Consequently, farming in such regions is more or less a hazardous occupation and the agricultural population somewhat transitory.

**Procedure:**

A. Till to conserve moisture.
B. Grow drought-resistant crops.
C. Seed properly.
D. Cultivate thoroughly.

**A. Till to conserve moisture.** The loss of water through surface runoff must be prevented as far as possible. This necessitates maintaining the surface soil in such condition that it will absorb rain water rapidly. Plowing increases the rate at which water is absorbed, and the depth of plowing influences the amount which is absorbed. Therefore, plow to a depth of 7 or 8 inches promptly after crops are harvested. The lister can often be used to advantage instead of the moldboard type of plow. With clay soils, which when compacted absorb water very slowly, it is essential that plowing be done promptly.[9]

Practice deep, fall plowing for the spring-seeded crops. Leave the ground in the rough over winter as snow will be held on the field more effectively. Disk or harrow in the early spring to form a surface mulch. Repeat the operation as often as necessary prior to seeding in order to prevent the loss of soil moisture by evaporation. Plow winter-wheat ground as soon as practicable after the preceding crop is removed. If too dry to plow, disk to lessen surface evaporation and to prevent loss of water through transpiration by weed growth. This disking will also increase the absorptive power of the soil, and should be repeated as conditions necessitate until sufficient rain water is absorbed to make it possible to plow the land. The lister can often be used to advantage in the planting of corn and other rowed crops.

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[9] See Chapter IV for tillage implements and operations.

Provide for the maintenance of the organic-matter content of the surface soil. Organic-matter maintenance is exceedingly difficult in dry climates since the production of a green-manure crop is a drain on the available moisture, and the decomposition of any organic material incorporated with the soil uses up considerable amounts of water. Nevertheless, unless provision is made for replenishing the organic matter, the absorptive power of the soil is reduced, it becomes less retentive of moisture; and with light-textured soils wind erosion may become a more serious menace to the successful production of crops. Green-manure crops should not be plowed under immediately preceding the planting of a regular crop. Manure or crop residues should be applied and plowed into the soil in the fall.

If a crop is to be seeded on freshly plowed land, roll the soil as soon as plowed, using the corrugated type of roller. The subsurface packer, an implement somewhat similar to the cultipacker, has been devised especially for dry-land farming and is a very effective type of roller to use. Follow the roller with a spike tooth or drag harrow to produce a surface mulch.

At one time summer fallowing was employed extensively in the semi-arid sections. It is not used to any great extent today and can hardly be considered a part of modern dry-land farming. The practice consists of producing a crop only every other year, and in alternate years of conserving moisture by means of a fallow. This fallow necessitates frequent summer tillage to kill weeds and to maintain a satisfactory surface mulch. It is at best an expensive system and will seldom prove an economically sound practice.

**B. Grow drought-resistant crops.** Crops vary in their water requirements.[10] In dry-land farming, choose those that make the most efficient use of water. Such crops are often termed *drought-resistant.* The small grains, especially wheat, the sorghums, and alfalfa, are outstanding examples. In addition, plant only varieties which have been developed in dry sections and are known to be especially suited to arid conditions. It is important to make certain that the seed to be sown was actually produced in a dry climate.

Wheat, chiefly because of its high drought resistance, is well suited to dry-land farming. In fact, it is the important cash crop of the semi-arid West. Although yields are normally lower than in sections having greater rainfall, the quality is better. Choose the hard, red wheats, such as Turkey red, for fall seeding, and hard varieties of spring wheat, like the durum, if seeding is to be done in the spring. Emmer and spelt, peculiar dry-land types of wheat, may be grown if the crop is to be fed to stock. They are especially drought-resistant but have been found unsatisfactory as cash crops. Other small grains, such as rye, oats, and barley, are also fairly well suited to a semi-arid climate.

Of the cultivated crops, consider the production of sorghum, Milo maize, and Kaffir corn for forage. Do not attempt the production of field corn except where the temperature is especially favorable and the rainfall in excess of 15 inches. If the soil and temperature are suitable, include potatoes as a cash crop. Good yields are sometimes secured without irrigation when the rainfall is from 12 to 15 inches.

Grow alfalfa in preference to any other hay crop; and if livestock is kept, consider sweet clover as a pasture crop.

[10] See Table V, Chapter II, for water requirements of plants.

These two legumes are especially well suited to dry-land conditions. Field peas may be grown in the cooler areas, and cowpeas in the warmer sections. It is not considered good practice to have land in alfalfa for long periods because the crop draws heavily on the moisture reserve of the subsoil and may so exhaust it that other crops following the alfalfa will not yield well. Sweet clover, as well as alfalfa, is adapted to dry conditions, not because of a low moisture requirement but on account of its ability to utilize, by means of a deep root system, the water supply of the subsoil.

Fig. 67. Sorghum—A Good Dry-Land Crop.

Of the cultivated crops, consider the production of sorghum, Milo maize, and Kaffir corn for forage where dry-land farming is practiced.

Besides the water requirement of crops, the season in which growth is made in relation to the distribution of the rainfall is an important factor to consider in choosing the crops to grow. Until experience justifies a change, depend on the crops that are produced most successfully by the better farmers of the community. Establish a systematic rotation, including at least one cultivated crop followed by a small grain. If alfalfa is grown, incorporate it in the grain rotation.

**C. Seed properly.** Seed the crops at half the rate used in humid sections. For example, 3 pecks of wheat or a bushel of barley to the acre is an adequate seeding in dry-land farming. One-half to one-fourth the normal number of alfalfa plants to the acre will suffice. Too large a number of plants to the acre will overtax the moisture supply, resulting in reduced yields. Except in heavy soils, seed somewhat deeper than in humid sections. Small grains may be seeded 2 to 3 inches deep with safety. Use the presswheel grain drill for seeding the small grains, especially on light soils or where at seeding time the soil is particularly dry. The rowed crops, such as corn and the sorghums, should be planted in furrows several inches deep, these to be filled later with soil when the crop is cultivated. Where the seed-bed has been properly compacted and moisture conserved with a surface mulch, there should be sufficient water for germinating seed when planted in this way. The time of seeding is of even greater importance than in humid regions. Seeding dates vary with the different sections. Seed at the time considered best for the local community.

**D. Cultivate thoroughly.** Cultivate the rowed crops frequently and to a somewhat greater depth than is advised in humid climates.[11] First of all, weeds must be killed; but, in addition, the crops must be cultivated frequently to conserve moisture. Level but shallow cultivation should be given at sufficiently frequent intervals to maintain a fine soil mulch 2 to 3 inches in depth. Plan to cultivate promptly after every rain that packs down and penetrates below the mulch. Harrow small grain until it reaches a height of 6 inches. Established alfalfa fields may also be harrowed to advantage. In dry-land farming cultivate crops with the idea of conserving for their use the water which has been stored in the soil and in addition as much as possible of the current seasonal rainfall. Crop yields will more often be determined by the water supply than by any other factor.

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[11] See Chapter IV for cultivation of crops.

## 8. Controlling Soil Erosion

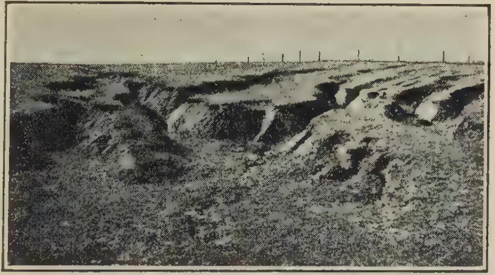

Fig. 68. Soil Erosion. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Erosion is responsible for soil depletion over vast areas.

Erosion is responsible for soil depletion over vast areas. Its control is an important factor in the maintenance of the productivity of the soil throughout the humid sections of the country. In the southern states erosion is especially serious because of frequent torrential rainfall, the low organic-matter content of the surface soils, and the scarcity of good sods. In much of this section the ground seldom freezes; it therefore remains subject to erosion throughout the winter months. Under such conditions strenuous measures have, of necessity, been resorted to in the control of erosion. The degree, nature, and distribution of erosion in the United States are indicated roughly in Fig. 69.

Land ruin as the result of uncontrolled erosion has recently been recognized as a national problem. Carefully planned erosion studies have been established in a number of states, and the Federal Soil Conservation Service is doing extensive erosion-control work throughout the country. Information is being secured on the rate of loss of soil material under different cropping and soil-management practices. This information should prove of inestimable value in the control of soil erosion in farm practice.

There are two important types of water erosion: *gullying* and *sheet erosion.* The former, which is the more apparent, removes both surface soil and subsoil, and not only reduces

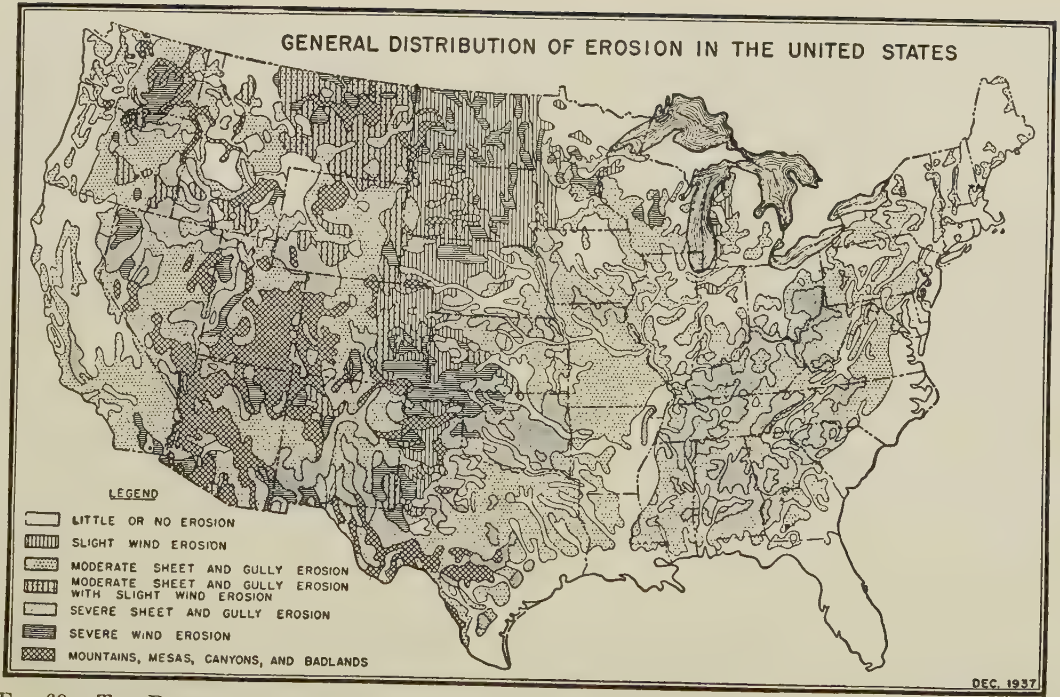
GENERAL DISTRIBUTION OF EROSION IN THE UNITED STATES
LEGEND
LITTLE OR NO EROSION
SLIGHT WIND EROSION
MODERATE SHEET AND GULLY EROSION
MODERATE SHEET AND GULLY EROSION WITH SLIGHT WIND EROSION
SEVERE SHEET AND GULLY EROSION
SEVERE WIND EROSION
MOUNTAINS, MESAS, CANYONS, AND BADLANDS
DEC. 1937

FIG. 69. THE DEGREE, NATURE, AND DISTRIBUTION OF EROSION IN THE UNITED STATES. (U. S. Dept. of Agr. Yearbook, 1938.)

the acreage of tillable land but also lessens the efficiency in crop production, owing to the irregularly shaped areas between the gullies. Sheet erosion is the gradual washing away of the surface soil from the sloping areas. Some of the material may be deposited in the low areas, but to a greater or less extent it is carried away by streams. Though less conspicuous than gullying, sheet erosion over a period of years may remove enormous amounts of productive surface soil; and unless it is controlled the surface soil will ultimately become so shallow that a sufficiently deep seed-bed cannot be prepared without plowing into the subsoil. This type of erosion is prevalent throughout the grain and livestock sections of the North and accompanies gully erosion in the South. Both gully and sheet erosion can be materially lessened, if not entirely controlled, by proper soil management.

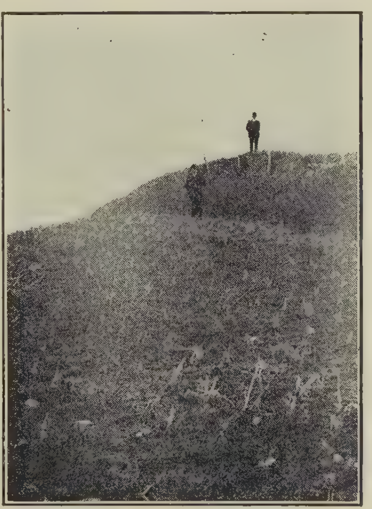

FIG. 70. SHEET EROSION.

Eight to 10 feet of soil have been washed away by sheet erosion from the cultivated field in the foreground.

Though less conspicuous than gullying, sheet erosion over a period of years may remove enormous amounts of productive soil.

A third type of soil erosion is known as *wind erosion.* Sandy soils, as well as peat and muck, are susceptible to it. Injury due to the blowing of the surface soil is most common in the prairie states. Although erosion is more severe in some sections than in others, there are few farms on which some injury is not apparent as the result of either soil or wind erosion, or both.

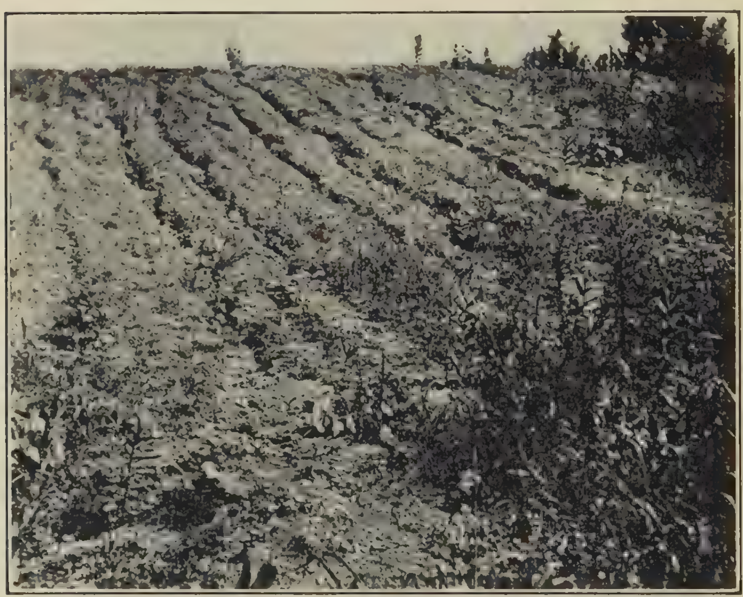

FIG. 71. GULLY EROSION. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Both gully and sheet erosion can be materially lessened, if not entirely controlled, by proper soil management.

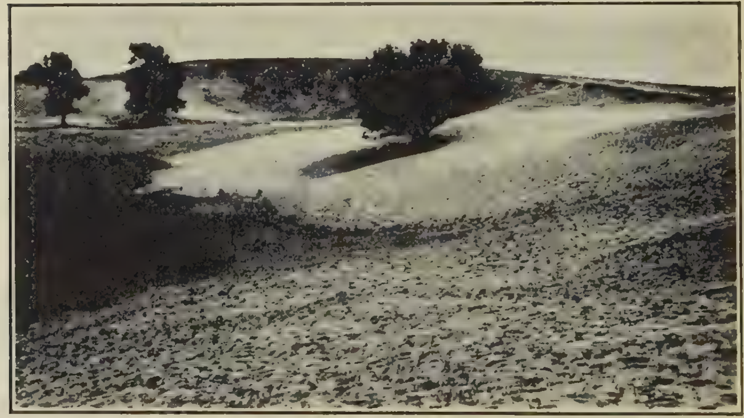

FIG. 72. WIND EROSION.

Sandy soils, as well as peat and muck, are susceptible to wind erosion.

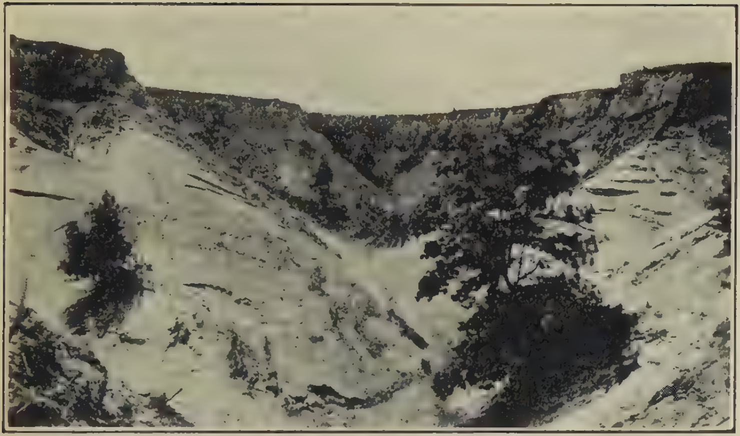

FIG. 73. A LARGE GULLY.

The best way to prevent the formation of large gullies is to fill the small ones promptly.

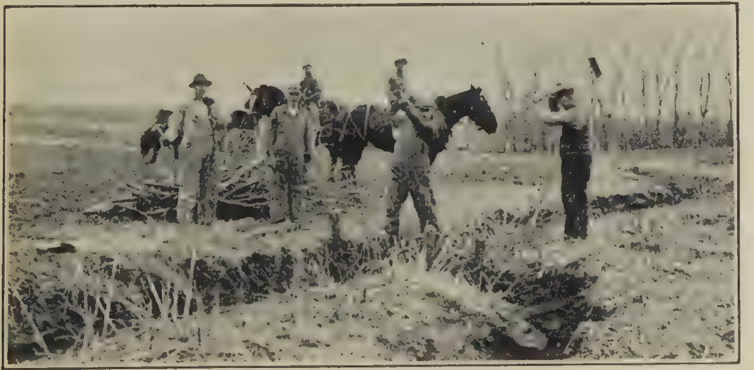

FIG. 74. BUILDING A BRUSH DAM. (Agronomy Dept., Neb. Agr. Exp. Sta.)

Construct brush dams for stopping moderate-sized gullies.

**Procedure:**

A. Fill gullies.
B. Grow sod crops and cover crops.
C. Manipulate the soil properly and farm on the contour.
D. Practice strip cropping.
E. Construct diversion ditches and terraces.
F. Reduce injury from wind erosion.

**A. Fill gullies.** Small gullies can be filled easily, but large ones are difficult and expensive to eradicate. The best way to prevent the formation of large gullies is to fill the small ones promptly. Fill the small gully with straw, weeds, or similar material, and cover by plowing several furrows on either side, throwing them to the center of the ditch. Level, and seed to a rank-growing crop like rye, millet, or Sudan grass. If a sod strip is necessary to prevent the reforming of the gully, seed a grass mixture.[12]

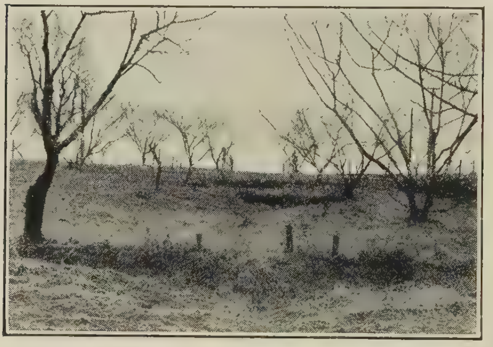

FIG. 75. SERIES OF THREE BRUSH DAMS.

Brush dams should be constructed at such frequent intervals that the top of one is on the level with or slightly above the base of the adjoining one up the gully.

Construct brush dams for stopping moderate-sized gullies. Pack the brush in the gully with the butts upstream. Use plenty of brush so that, when thoroughly tramped down, the ditch will be practically level-full with the center slightly lower than the sides. Drive a row of stakes through the brush about one-third the distance below the butts. Now bind the tops together with wire, and fasten securely to the stakes with staples. When this is done, drive the stakes down until the wire firmly binds the brush and the stakes are well anchored in the soil underneath. Dams of this type should be constructed at sufficiently frequent intervals so that the top of one is on the level with, or slightly above, the base of the adjoining one up the gully. Fill in above each brush dam with a layer of straw, weeds, or cornstalks. When the ditch is filled with sediment between dams, plow and seed as with the small gullies. Unless a sod strip replaces the gully, construct an occasional low ridge across the filled-in area so the water will be diverted to either side. A diversion ditch emptying into woodland or onto a permanent pasture sod may be necessary to prevent the formation of new gullies.

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[12] See page 422 for grass mixtures.

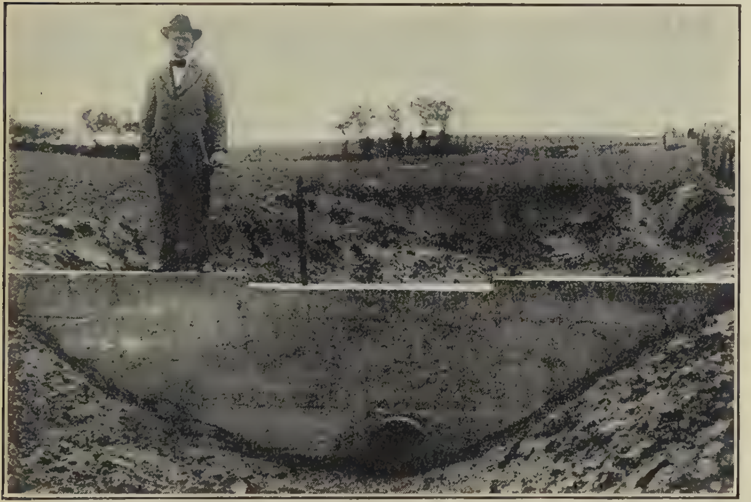

Fig. 76. Concrete Dam. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Dams of this type are expensive and should be used only where the soil is subject to serious erosion and where their use is absolutely essential to the protection of good farm land.

If the gully is too large for the successful use of brush, either earth or concrete dams must be used. With these larger dams, use a tile to carry the water under the dam as shown in Fig. 76. A vertical tile just above the dam permits the water to enter when it rises above the upper edge of this tile. As sediment accumulates, the height of this intake is raised until finally the gully becomes filled to the level of the top of the dam. Construct a wooden or concrete spillway where the water emerges from the tile below the dam. Dams of this sort are expensive and should be used only where the soil is subject to serious erosion and where their use is absolutely essential to the protection of good farm land.

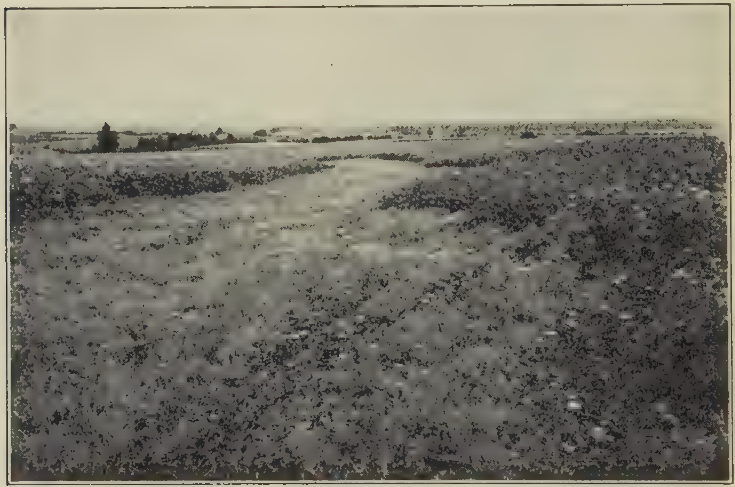

FIG. 77. SOD STRIP TO PREVENT EROSION. (Soil Erosion Service, U. S. Dept. of Int.)

If fields in which gullies may form must be plowed, the natural drainage ways should be seeded and maintained in sod.

**B. Grow sod crops and cover crops.** Erosion is most serious where tilled crops are grown, and can be largely prevented by maintaining a good grass sod. Fields subject to erosion should, when it is feasible, be used for permanent pasture and long lays of hay. Plow such fields at infrequent intervals, if at all, and avoid so far as possible using them for the production of crops requiring cultivation. When plowing becomes necessary, reseed promptly to a sod crop. If fields in which gullies may form must be plowed, the natural drainage ways should be seeded down and maintained in sod unless other means of erosion prevention are utilized. Such fields should be liberally fertilized or manured to assure a dense sward. Erosion may develop in thin sods which occur on depleted soils, but a thick pasture or meadow sward reduces sheet erosion to the minimum and prevents gullies from starting. Sod strips, if properly located, will handle the surface runoff so that gully erosion will not start. When necessary for the maintenance of a heavy sod, top-dress these strips with manure or fertilizer.

Plow sod land in the spring rather than in the fall so that the soil may have the protection of the sod during the winter. Where fall plowing of sod on areas subject to erosion is essential for the success of the following crop, erosion can be reduced, if not completely controlled, by leaving sod strips at least a rod wide at intervals of 100 feet or more, depending on the per cent of the slope. These sod strips should be approximately on the contour. They may be plowed in the spring before the seed-bed is prepared.

Erosion is less serious with small grains than with cultivated crops. Winter cover crops, such as rye, vetch, and clover, are helpful in reducing surface washing. Seed regularly each fall on land subject to erosion unless it is protected by a sod. Where the control of erosion is so expensive that cultivated crops cannot be produced profitably, grow grass and clover instead, and utilize as meadow or pasture. If erosion cannot be controlled advantageously when the land is in sod, it might well be planted to forest trees, as such soils cannot be utilized advantageously for the production of field or pasture crops. For the control of wind erosion, use sod where the soil is adapted to grass. In the event of serious wind erosion on very sandy soils and on peat and muck, plant trees as windbreaks.

**C. Manipulate the soil properly and farm on the contour.** Plow relatively deep where a soil is subject to erosion. This will increase the absorptive capacity of the soil, reducing surface runoff. Maintain the organic-matter content of the surface soil at as high a level as is practical, since organic matter increases absorptive capacity. Always plow the slope crosswise so as not to leave dead furrows running up and down the hillside. The swivel plow can be used to advantage on steep slopes.[13] Where tilled crops are grown, run the rows across the slope to avoid cultivating up and down the hill, a practice conducive to soil erosion.

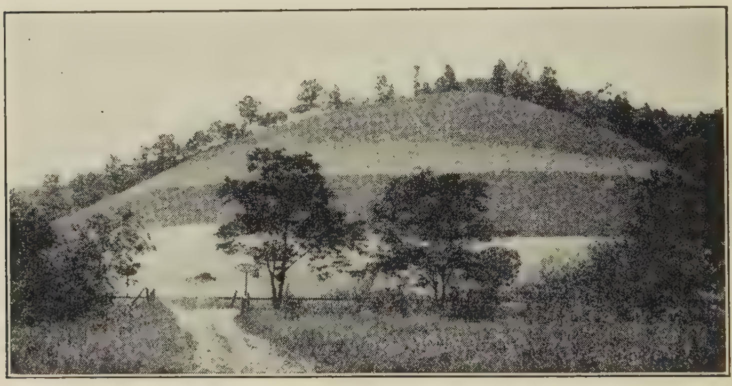

Fig. 78. Contour Farming.

In sections where the soil is especially susceptible to erosion, it is very essential that all tillage operations follow the contour of the surface.

Give the crops level cultivation. Even when seeding small grain, the drill should not be driven up and down the slope as the wheels and the hoes will leave depressions into which surface water may drain and start erosion. By seeding crosswise of the slope, these depressions, with the ridges between, tend to hold the water until it is absorbed by the soil. In sections where the soil is especially susceptible to erosion, it is very essential that all tillage operations follow the contour of the surface. This practice, termed *contour farming,* should be employed in connection with rotation of crops as a means of reducing erosion. Where the soil is subject to wind erosion, plant the crops promptly after the land is plowed.

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[13] See Chapter IV for types of plows.

Even though a fairly satisfactory job of contour farming may be accomplished without first locating contour lines, it is generally advisable, especially where accuracy is essential to erosion control, to locate contours by means of a land level. This is not a difficult procedure. All the equipment needed is a farm level, a ranging pole, or any straight, lightweight pole 6 to 7 feet in length, a supply of building laths, and a rubber band or elastic which will fit snugly around the pole. Start at one edge of the field across which a contour is to be run. Set the level up about 50 paces in from the edge of field and level it accurately. Have the pole held upright at the edge of the field. The base should rest on the surface of the ground. Sight through the level and have the rubber band on the pole moved up or down until it is on the level with the instrument. Have a lath stuck in the ground at the position of the pole. The pole should now be moved 10 to 12 paces in the direction of the level and held vertical as before. Care should be taken not to change the position of the rubber band. From this point have the pole moved up or down the slope until the rubber band is again on a level with the instrument. Mark this new position with another lath, proceed in the same manner, and locate additional laths at 10 to 12 paces on the same level until a distance of 50 to 60 paces beyond the position of the level has been reached. It now becomes necessary to move the level. It should be advanced some 50 or 60 paces beyond the pole. Again level the instrument and sight back on the pole which should not be moved from the last position while the level is being advanced. Again have the rubber band raised or lowered until it is again on the same level as the instrument. Continue the procedure until the opposite side of the field is reached. Obviously, the laths will indicate a line which is on the same contour or level. In the same manner locate sufficient additional contour lines across the field so plowing and seeding may be done on the contour.

**D. Practice strip cropping.** On broad sloping hillsides, where it is necessary to produce rowed or drilled crops and contour cropping alone is not adequate to prevent erosion, different crops may be grown in alternate strips crosswise of the slope. To be most effective these strips should follow the contour of the field.

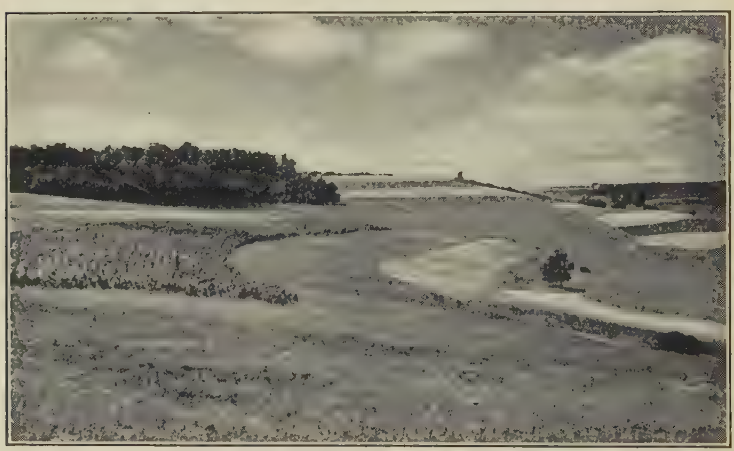

FIG. 79. STRIP CROPPING. (Soil Erosion Service, U. S. Dept. of Int.)

One of the most practical means of reducing erosion is to grow crops in alternate strips or belts.

Since sod crops are most effective in reducing erosion, it is desirable that every second or third strip be in hay. Adjoining strips should never be in cultivated crops. A small grain crop may adjoin a strip of a cultivated crop, but, wherever feasible, a strip of a sod crop should be immediately above or below each strip of a cultivated crop.

A desirable arrangement of crops on strips for a five-year rotation of corn, oats, wheat, and two years of hay is as follows:

| Strip | 1st Year | 2nd Year | 3rd Year | 4th Year | 5th Year |
|---|---|---|---|---|---|
| 1 | Corn | Oats | Wheat | Clover | Timothy |
| 2 | Clover | Timothy | Corn | Oats | Wheat |
| 3 | Oats | Wheat | Clover | Timothy | Corn |
| 4 | Timothy | Corn | Oats | Wheat | Clover |
| 5 | Wheat | Clover | Timothy | Corn | Oats |

The width of the strips should depend on the degree of slope, the susceptibility of the soil to erosion, and the expected intensity of rainfall. Strips narrower than 50 feet are impractical, and so far as possible they should be 100 feet wide or even more. Except where soil and climatic conditions are favorable for erosion, the strips may safely be as wide as 100 feet provided the slope does not exceed 10 per cent. Under similar conditions 75-foot strips may be used on a 10 to 15 per cent slope, and 50-foot strips on 20 per cent slopes. Even where soils are well drained and not particularly subject to erosion, slopes with a steeper grade than 20 per cent should be used exclusively for sod crops. Where conditions are more favorable to erosion, a slope of 15 per cent and, under extreme conditions, slopes of 10 to 15 per cent should be used for permanent pasture or continuous hay production. A plan for strip cropping, including location of strips and diversion ditches, is graphically shown in Fig. 80. The location of the crops of the five-year rotation is indicated.

In establishing a system of strip cropping, it is often desirable to remove fence rows and to throw two or more fields together in order to avoid short strips. Before deciding on the width of strips, the approximate degree or per cent of slope should be determined. To do this set up the level at the lower edge of the field and sight up the hill. Note the point up the hill which is on the same level as the instrument. Mark this point with a stake. Then measure the distance from the instrument to the stake. Also determine the height in feet of the level above the ground surface exactly underneath. Now multiply this latter figure by 100, and divide the result by the number of feet between the instrument and the stake to secure the per cent of the slope. Repeat this process as frequently as necessary to obtain sufficient information about the degree and variation of slope on which to determine the desired width of strips. If in doubt as to the width of strips, consult your college of agriculture, county agricultural agent, or a competent agricultural engineer. Knowing the character of soil and the per cent of slope, one may secure from either of these sources information as to the required width of the crop strips.

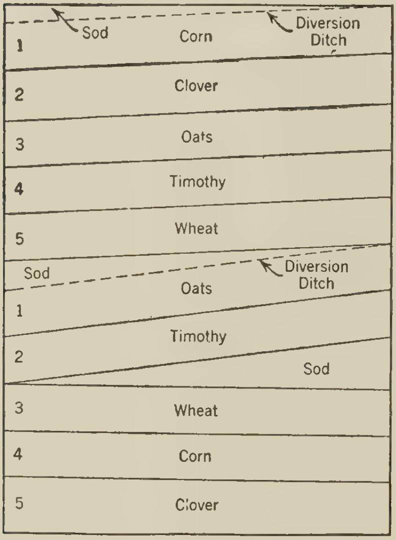

Fig. 80. A Plan for Strip Cropping.

After the width of strips has been determined, start at the lower side of the field and lay out a contour line across the field, starting from a point on one side of the field, the distance of the strip above the lower corner. In laying off the contour, follow instructions given for establishing contour farming.

The upper edge of the strip may be located by measuring up the slope from each stake, marking the established contour line. Use care that all measurements are made at approximate right angles to the contour line. In conjunction with these measurements, drive stakes or laths, marking the upper edge of the strip. Boundaries of additional strips may be located in the same manner by measuring up the slope from the last one established, provided the slope is uniform. In the great majority of cases variation in degree of slope will necessitate laying out every second- or third-division strip on the contour. Refer to Fig. 80.

As a result of irregularity of slope, some strips may be wider or narrower than others, and correction strips or part strips may have to be employed. Such correction areas cannot conveniently be used for cultivated crops. They should be cropped with hay or a rotation of small grains and hay as indicated in Fig. 80.

After the boundaries between strips are located for the whole field, they should be marked more permanently by plowing a furrow along each. It is desirable to establish a system of strip cropping while a field is in hay, since the common rotations can more readily be established and erosion more effectively controlled the first year.

**E. Construct diversion ditches and terraces.** A *diversion ditch,* as the name implies, is an artificial drainage way constructed to divert water from its natural direction of flow. In function it is similar to a terrace. A diversion ditch is most often used near the top of a slope as a means of diverting headwater from flowing down across a field. Such a ditch should empty into woods, a stream-bed, or onto a well-established pasture sod where it will do no harm. It is sometimes necessary, in connection with strip cropping, to install several such ditches along diversion strips where the slope is too steep for strip cropping in itself to control erosion effectively. See Fig. 80.

Land should be terraced only as the last resort in controlling erosion. In addition to entailing a large initial expense, terraces require constant repair; and even when they are properly located, erosion continues between the terraces, and considerable surface soil is washed away at the end of each terrace. Wherever practical, grow sod crops on land which would require terracing for erosion control if tilled crops were grown. To be effective, terracing should be done in conjunction with, rather than separate from, the other methods employed in the control of soil washing. A *terrace* consists of a ridge of sufficient height to catch the water, and which has a gradual but uniform grade to cause the water to flow around the slope until it is deflected from the field. The surface drainage above a terrace, the same as the water of a diversion ditch, should empty into woodland, a stream-bed, or onto permanent sod.

Fig. 81. Diversion Ditch.

A diversion ditch is most often used near the top of a slope as a means of diverting headwater from flowing down across a field.

Diversion ditches and terraces are laid out in the same way and constructed similarly. For both, the fall should be uniform, or with long ditches or terraces, gradually increased towards the outlet. The degree of fall will depend not only on the length of the ditch or terrace, but also on the rate and intensity of rainfall and on the character of the soil. It should seldom be less than 3 inches and practically never over 36 inches to the hundred feet. Before laying out either diversion ditches or terraces, secure reliable information as to degree of fall for your local climatic and soil conditions.

In locating diversion ditches or terraces a land level and a rod or pole 8 to 10 feet in length will be needed. Proceed as follows: Set up the level where the ditch or terrace is to start and work downgrade. Drive a stake or lath to mark the starting point. In order that instructions be specific, assume that the fall is uniform and at a rate of 6 inches to the hundred feet. Measure the exact height of the instrument above the ground level. Now measure this same distance from the base of the rod or pole and mark preferably with a rubber band or elastic as suggested in laying out contour lines. Slip the band exactly 6 inches up the rod. Measure or pace a distance of 100 feet in the approximate direction in which the ditch or terrace will be located. At this point have the rod held vertical with the base resting on the ground surface. Sight through the level and have the pole moved up or down the slope until the band on it is exactly level with the instrument. Mark this point with a stake or lath. Raise the band an additional 6 inches on the pole, and locate the position of the ditch or terrace an additional 100 feet from the instrument.

When it becomes necessary to move the level to a new position down the slope, have the pole held at the last 100-foot location determined. After the instrument is leveled in its new location, sight back on the rod and have the band moved down until it is on the exact level with the instrument. Again slip the band up 6 inches on the rod and proceed as before. In some fields it may be desirable to locate the position of ditch or terrace at 50-foot intervals, while in other instances 200-foot intervals may be adequate. For 50-foot intervals the band should be moved 3 instead of 6 inches up the rod, and for 200-foot intervals the band should be moved up 12 inches on the rod.

Obviously, the procedure in determining the location of a diversion ditch or a terrace is similar to that in locating a contour line—the only difference being that in the former instance the band must be moved a uniform distance up the measuring rod for each unit distance down the grade, whereas with the latter it remains in the same position on the rod for each setting-up of the land level.

While it is not difficult to locate an individual diversion ditch or terrace, it is not always a simple matter to determine how many ditches or terraces may be needed in a given field to keep erosion under control. Especially where a series of terraces is to be laid out, a competent engineer should be employed to determine the number required and the height to which they should be constructed.

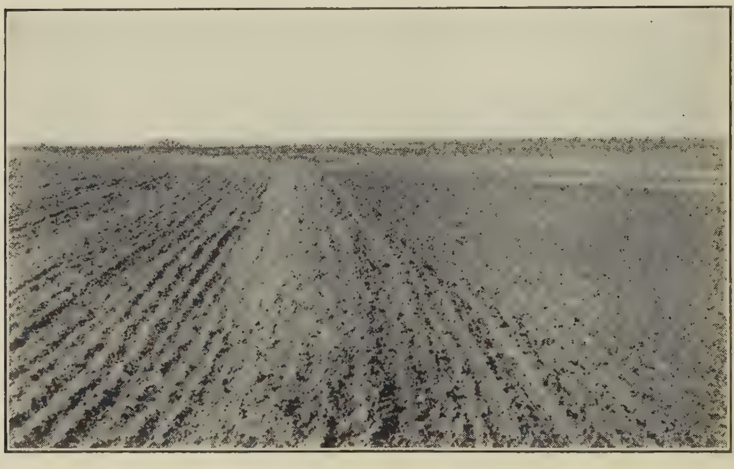

Fig. 82. A Terrace. (Soil Erosion Service, U. S. Dept. of Int.)

**Land should be terraced only as the last resort in controlling erosion.**

After the location of a diversion ditch has been determined, proceed as follows in its construction: First, plow a strip 20 to 40 feet wide immediately above the marked ditch line. Then, with a road scraper or a bulldozer, throw the soil downhill until a broad ridge 2 to 3 feet high has been built up with a ditch 12 to 18 inches deep formed above the ridge and about one-third of the way across the plowed strip from the upper edge. Then harrow the whole strip and seed with a pasture-seeding mixture adapted to the soil and climatic conditions.[14]

After the terrace is located, plow a deep back furrow along the line of stakes. Continue plowing, throwing the furrow slices in from both sides, until a strip 12 to 15 feet wide is plowed. Drag the plowed soil with a regular terrace drag, throwing it in from both sides until a broad ridge is formed, having a height of 15 inches at the center and a uniform slope to the two sides. A road scraper, either horse or tractor type, may be used instead of the terrace drag. After the terrace has settled for several weeks, check it with a level, making certain that there are no low spots which might overflow. Where the crest has settled below an elevation of 12 inches, rebuild to at least this height by additional scraping. Inspect a new terrace after every heavy rain. Fill in any places that have settled unduly, and repair any breaks that may have occurred. Similar attention should be given to diversion ditches.

Attention should be given the terraces with every plowing of the field. Unlike diversion ditches, which are commonly maintained in permanent sod, terraces are plowed and cropped in the same way as the rest of the field. In plowing a terraced field, plow down the center of the terrace, first throwing the furrows in.[15] Starting with this back furrow, continue plowing out from the center of the terrace. This will tend to rebuild the terrace ridge and leave the dead furrow in the middle of the space between terraces. Plant crops on the contour with the terraces, and cultivate them in like manner. Employ strip cropping, including sod crops when practical, on terraced fields.

**F. Reduce injury from wind erosion.** Although wind erosion of farmed soils is less injurious than water erosion, nevertheless much damage has resulted from the blowing of surface soil. The prevention of this type of erosion is a real problem on many farms. Sand, muck, and peat are especially subject to wind erosion, and it is more serious in arid or semiarid than in humid sections. It is more severe in dry summers than in wet ones. Dust storms were very severe in certain states of the Great Plains in the summer of 1934, and have been troublesome ever since. These dust storms are the result of a series of dry years in a section where a large proportion of the land is in wheat or other non-sod crops and where there is little timber growth to reduce the velocity of the wind. Crop injury may result even on the heavier types of soil.

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[14] See Chapter X for pasture-seeding mixtures.

[15] See Chapter IV for information on plowing.

Keeping land in sod is the most practical way of controlling wind as well as water erosion. Unfortunately, very sandy soils are not particularly suited to the production of grass crops, nor are they especially good for permanent pastures. Where rotation crops are grown, till the soil at right angles to the direction of the prevailing winds, prepare the seed-bed promptly after plowing and seed the crop immediately. Avoid preparing too fine a seed-bed. So far as possible, use the type of implement which will leave the surface somewhat cloddy. Do not use a smooth roller or a plank drag.

Where the surface soil is deep, use a lister instead of a moldboard plow. Strip cropping can sometimes be used to advantage. Windbreaks consisting of rows of trees or shrubs, or even of board fences, may be employed where the production of high-value crops can be justified.

Considerable areas of marginal or submarginal sandy land are being farmed. Much of it is subject to serious injury by blowing. With the development of a sound land-utilization program many of these farms will, in all probability, be thrown out of cultivation and seeded to grass or forested.

## GENERAL INFORMATION

### 1. Character of Soil Water

There are three forms of soil water. The first form, called *free* or *gravitational water*, is that part of the water which passes down through the soil and is lost as underground drainage. The remainder of the water is held by the soil as films around the soil grains. That which is loosely held until evaporated from the surface, or utilized by growing plants, constitutes the second form of water. It is capable of moving freely in any direction and is called *capillary water.* The third form, *hygroscopic water,* is held very tightly as extremely thin films around the soil grains. There is no distinct division between these three recognized forms of soil water, but rather a gradual transition from one into the other; nevertheless, it is necessary to know the character of each in order to understand the functioning of soil water as a whole.

**A. Free water.** The free water flows downward through the pore spaces of the soil. In inadequately drained soils it may fill the pore spaces, producing what is called a saturated or water-logged soil. The water table represents the location of the upper level at which the pore spaces are filled with free water. Free water is injurious to crops if it accumulates in the area of root growth. The function of drainage is to remove the free water and prevent its accumulation in the upper 2 to 4 feet of soil. Free water is of value in replenishing the supply of capillary water. For this reason it is desirable to have the water table just below the zone of root development.

**B. Capillary water.** It is in this form that water is utilized by plants. The root hairs take it in from the loosely held films surrounding the soil grains. As the root hairs draw on the films with which they come in contact, surface tension causes a movement of capillary moisture to the films of reduced thickness, and thus the supply of capillary water is replenished. In the same way this form of water moves upward by capillarity as evaporation takes place from the surface of the soil.

Plant growth is dependent on an adequate supply of capillary water. By means of this water the soil plant-food enters the plant. The amount most favorable for growth—that is, the optimum moisture content of soils—varies with the character of the soil. It is approximately 20 per cent for sand, 30 per cent for clay, and 200 per cent for muck. As the amount is reduced below the optimum, growth is retarded; and in extremely dry seasons crops may wilt and even die because of an inadequate supply of capillary water.

**C. Hygroscopic water.** The hygroscopic water is of little, if any, agricultural importance. It is the water that remains when a soil is thoroughly air-dried. This form of water is held tightly by the soil grains, does not move under normal conditions, and cannot be utilized by plants. Much of it is associated with the colloidal material and the organic matter. It can be forced from the soil by heating to the boiling point. The amount varies from 2 per cent in sand to as much as 40 per cent in muck. Ordinary loams contain 4 to 6 per cent.

Understanding the functions of these different forms of water, one can appreciate the necessity, in practical soil management, of removing excessive amounts of free water by artificial drainage, as well as the importance of maintaining an adequate supply of capillary water for the growth of crops.

## 2. Why Drainage Is Essential

Wet soils are the result of one or more of the following three conditions: (1) an inadequately developed surface drainage; (2) seepage due to underground water coming to the surface; (3) impervious subsoil. Any one of these conditions may result in crop injury due to the slow removal, or the accumulation, of free water in the surface few feet of the soil.

The direct injury to plants is due to the filling of the pore spaces by free water, and forcing the air out of the soil. An adequate supply of air in the soil is absolutely essential for the growth of crops. It is likewise essential to the functioning soil bacteria, upon which plant growth is so dependent. The direct injury from poor drainage is the result of a reduced supply of soil air. The only means of remedying the difficulty is to remove the excess water and permit air to replace it. Drainage, then, can be said to improve the tilth of the soil since proper aeration is one of the essentials of good tilth. It can also be said to increase the available plant-food since the rate at which the soil supply becomes available is largely dependent on the activity of the soil bacteria.

Other benefits of drainage may be summarized as follows:

(1) It reduces drought injury.

This is due to the deeper root system developed in well-drained soils.

(2) It permits more efficient soil and crop management.

A well-drained soil dries quickly in the spring, permitting early seed-bed preparation. It also warms up more quickly than a poorly drained soil. As a result, spring crops can more often be seeded on time, a most essential requirement of successful production. Drainage also facilitates the cultivation of crops during the growing season. Through the drainage of low spots, fields are made uniform, and as a result can be farmed more economically.

(3) It reduces crop and soil injury.

Drainage reduces the winter injury done to crops by heaving. The pressure which forces the plants upward, breaking many of the roots and disconnecting the whole root system from its firm contact with the soil, is the result of expansion caused by the freezing of the free water in the surface soil. Sometimes soil erosion may be lessened by underdrainage; and, in irrigation farming, alkali injury may be reduced if not completely remedied.

(4) It increases the area of cropped land.

From the standpoint of an adequate food supply, drainage is beneficial in that it makes possible the reclaiming of land which, until drained, is unfit for cropping.

### 3. ILLUSTRATION OF CALCULATING DEPTH OF DITCH
(Refer to Fig. 83.)

Information necessary for calculations:

Length of ditch, 500 feet.
Depth at outlet, 3 feet.
Fall, 4 inches to 100 feet.

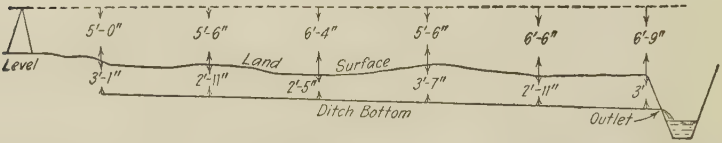

FIG. 83. GRAPHIC ILLUSTRATION OF CALCULATING DEPTH OF DRAINAGE DITCH.

Level readings:

| | | | | |
|---|---|---|---|---|
| At outlet | 6 | feet | 9 | inches |
| At first hub stake | 6 | " | 6 | " |
| At second " " | 5 | " | 6 | " |
| At third " " | 6 | " | 4 | " |
| At fourth " " | 5 | " | 6 | " |
| At upper end of ditch | 5 | " | 0 | " |

Calculations:

6 feet 9 inches + 3 feet = 9 feet 9 inches
9 " 9 " − 4 inches = 9 feet 5 inches
9 " 5 " − 6 feet 6 inches = 2 feet 11 inches depth at first hub stake

4 inches × 2 = 8 inches
9 feet 9 inches − 8 inches = 9 feet 1 inch
9 " 1 inch − 5 feet 6 inches = 3 feet 7 inches depth at second hub stake

4 inches × 3 = 12 inches
9 feet 9 inches − 12 inches = 8 feet 9 inches
8 " 9 " − 6 feet 4 inches = 2 feet 5 inches depth at third hub stake

4 inches × 4 = 16 inches
9 feet 9 inches – 16 inches = 8 feet 5 inches
8 " 5 " – 5 feet 6 inches = 2 feet 11 inches depth at fourth hub stake
4 inches × 5 = 20 inches
9 feet 9 inches – 20 inches = 8 feet 1 inch
8 " 1 inch – 5 feet 0 inches = 3 feet 1 inch depth at upper end

## 4. Kinds of Alkali and Crop Injury from Alkali

Alkali consists largely of the accumulation of such water-soluble salts as sodium chloride (common salt), sodium sulfate (Glauber's salt), sodium carbonate (salsoda), and sodium hydroxide (common lye). While other salts commonly occur in small amounts, these four are of greatest concern in alkali control. The first two are the so-called *white alkali,* and the last two are the so-called *black alkali.*

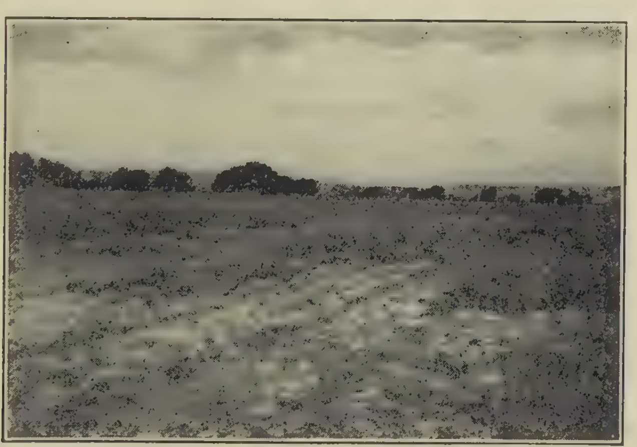

Fig. 84. Alkali Injury to Sweet Clover.

While plants secure nutrients from the soil solution, they cannot endure a high concentration of soluble salts.

While the salts which constitute white alkali may be readily leached from the soil if there is adequate underdrainage and a sufficient supply of irrigation water, those making up the black alkali salts are held by the soil colloids. Their composition must be changed before they can be leached out successfully. Where gypsum ($CaSO_4$) or elemental sulfur is incorporated with the soil, base exchange[16] takes place with the formation of sodium sulfate, which may be removed by leaching.

Most alkali deposits contain both white and black alkali. The formation of black alkali often accompanies the removal of the white alkali. An additional complication frequently encountered in the removal of alkali is the development of an undesirable physical condition in the soil which interferes with the downward movement of water, and thus reduces the effectiveness of further leaching. The soil becomes puddled and difficult to till. Farmers refer to it as the "freezing-up" of the soil. This condition is invariably associated with the presence of black alkali. While the presence of white alkali improves the structure of a soil, a relatively small amount of black alkali ruins the tilth, especially if the soil contains any material amount of clay. The application of gypsum or elemental sulfur has been found the most practical treatment to alleviate the difficulty.

While plants secure nutrients from the soil solution, they cannot endure a high concentration of soluble salts. The injury may be due to the concentration of the soil solution's becoming greater than that of the plant sap, resulting in interference with the normal movement of the solution into the plant roots.[17] The growth of many plants is retarded by excess chlorine, and most plants grow best when the soil is slightly acid. As might be expected, the hydroxides which largely constitute the black alkali are extremely toxic to plants, and it requires a relatively small amount to produce serious crop injury. In addition to a direct chemical effect which is injurious, the black alkali indirectly retards growth as a result of its adverse effect on soil tilth.

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[16] See page 51 for explanation of base exchange.

[17] See page 89 for discussion of the function of water in plant growth.

## COMMUNITY STUDIES

1. Visit a poorly drained area or field and determine the practicability of its being drained.

2. Visit a farm that has a tile system installed. Inspect the outlet, determining the method and efficiency of protection and whether the system is functioning. Secure information as to the date of installation, cost, and effect on crop yields.

3. If open-ditch drainage is used in the community, inspect such a drainage system. Is the land satisfactorily drained? Are the ditches clean? How often are they cleaned? Have weeds been kept down along the ditches? Estimate the percentage of a ditched field that is unfarmed because of the ditch system.

4. Estimate the proportion of farm land in the community which is in need of better drainage.

5. How many acres of unimproved land in the community need drainage to make the land suitable for cropping?

6. If practicable, locate and dig a drainage ditch, establish the fall, and lay a miniature tile system.

7. If in a section of low rainfall, make a field study of systems of dry-land farming and irrigation practices.

8. Locate and study examples of gully and sheet erosion in the community.

9. Visit, where available, a farm on which erosion-control practices have been established. List the methods used and note their relative effectiveness.

10. Locate a small gully and construct a brush dam, or find a place where a diversion ditch is needed and locate such a ditch with the proper fall and satisfactory outlet.

11. In communities where terracing is practiced, visit a terraced field and determine the effectiveness with which the erosion is controlled. In such a community, determine the location of, and stake out, a prospective terrace.

12. If strip cropping is practiced in the community, visit a farm on which this method of erosion control is being followed. List the crops grown and the width of the strips of each, and observe the effectiveness of the different crops in reducing erosion.

13. Where wind erosion is a problem, determine the means used in farm practice to control it.

## PROBLEMS

1. If the surface runoff is 25 per cent, how many inches of rainfall would be required to produce an optimum moisture content of a foot of water-free loam soil?

2. Calculate the depth of a drainage ditch at each 100-foot interval. The length of the ditch is 500 feet, depth at outlet 3½ feet, and fall 3 inches to the 100 feet. The level readings are as follows:

| | | | | |
|---|---|---|---|---|
| At outlet | 6 | feet | 10 | inches |
| " first hub stake | 6 | " | 7 | " |
| " second " " | 6 | " | 2 | " |
| " third " " | 6 | " | 6 | " |
| " fourth " " | 5 | " | 10 | " |
| " upper end | 5 | " | 9 | " |

3. Outline arrangement of crops for strip cropping where the rotation consists of two years of corn, one of oats, and three of hay.

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# CHAPTER IV

## TILLING THE SOIL

Tillage, essential for the profitable production of farm crops, includes plowing, harrowing, and dragging the soil in the preparation of the seed-bed, and cultivating the growing crop.[1] It constitutes one of the major items of expense in crop production. The operations must be performed thoroughly and with the minimum expenditure of labor. Good soil tillage economically performed is an absolute essential of profitable farming.

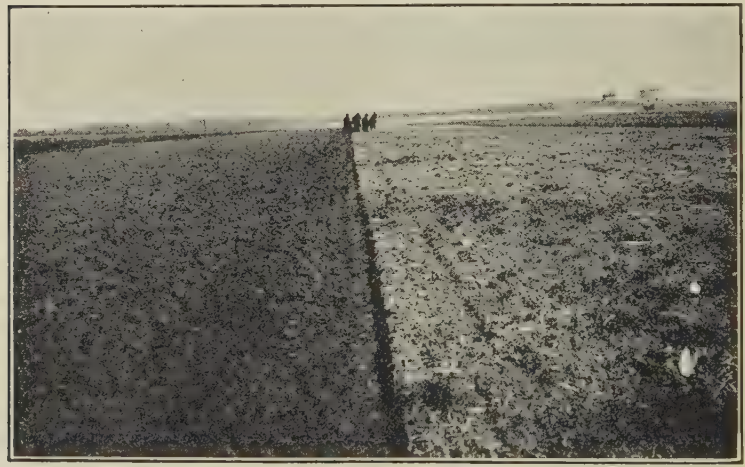

Fig. 85. Good Plowing. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Good soil tillage economically performed is an absolute essential of profitable farming.

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[1] See General Information at end of chapter for benefits of tillage.

**Operations:**

1. Plowing.
2. Preparing the seed-bed.
3. Cultivating the crop.

## 1. Plowing

Field soils become firm when left unstirred for several months. The weight of the soil and the compacting by rain tend to force the grains closer together. If the soil is of a clay character, it may become very hard and even impervious to water within a comparatively short period. Invariably, the soil must be loosened by tillage before a crop can be seeded successfully. This generally necessitates plowing, which constitutes the first tillage operation. Another object of plowing is to incorporate organic matter with the soil. Plowing consists of cutting narrow slices of the surface soil, throwing them to the side, and depositing them in a partly inverted position. In the process the moved soil is more or less broken apart. The depression left by the plow is called a *furrow.* The strip of soil moved by the plow, which varies from 8 to 18 inches in width depending on the size and set of the plow, is known as the *furrow slice.* When, in plowing, two adjoining furrow slices are thrown in opposite directions resulting in a double-width furrow, the depression between is termed a *dead furrow.* Similarly, when two adjoining furrow slices are thrown together from opposite directions, a ridge results which is known as a *backfurrow.*

**Procedure:**

A. Plan the plowing.
B. Plow at the proper time.
C. Plow to the proper depth.
D. Plow under organic matter.
E. Care for the plow.

**A. Plan the plowing.** Before starting to plow a field a plan must be determined upon. If a two-way plow is used, little planning is necessary as the plowing may be started at one side of the field and continued systematically across the field, a single furrow at a time. This is possible with a plow of this type because it throws all furrows in the same direction. Most plows are either right- or left-handed, depending on whether the furrow slice is thrown to the right or to the left.[2]

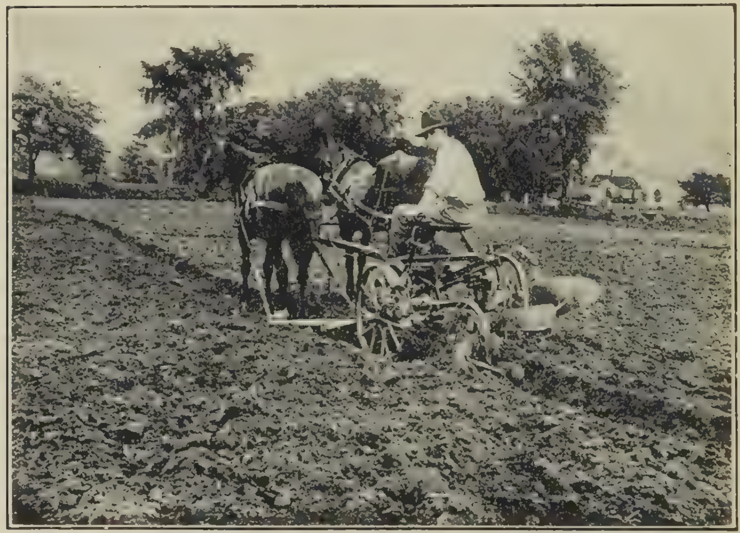

FIG. 86. TWO-WAY PLOW. (Agronomy Dept., N. Y. State Col. of Agr.)

If a two-way plow is used, little planning is necessary as the plowing may be started at one side of the field and continued systematically across the field, a single furrow at a time.

In plowing a small field with the ordinary type of breaking plow, start at one corner and plow around the entire field, throwing the furrow slices out. In a rectangular field, a dead furrow is left through the center on completion of plowing. When the field is again plowed, start by plowing through the center the long way of the field, reversing the whole operation and throwing the furrows in from both sides. This will produce a back furrow where the dead furrow was left by the previous plowing. Small, or irregularly shaped fields are invariably expensive to plow because of short furrows.

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[2] See General Information at end of chapter for different types of plows.

Most fields are sufficiently large to make it advisable to do the plowing in strips, which are known as *lands*. This necessitates deciding the width of the strips to be plowed and the laying off of the field into lands. Unless each land has a uniform width throughout its length, difficulty will be encountered, or at least time wasted, in completing the plowing, since the last few furrows of the land will not be continuous across the field. Consequently, in "striking out a land," that is, in plowing the furrows to mark out the strips, plow the furrows straight and exactly parallel. Straight furrows are indicative of good plowing and can be obtained only when those made in laying out the lands are themselves straight. Where plowed in this manner, dead furrows and back furrows necessarily occur alternately across the field. In laying out

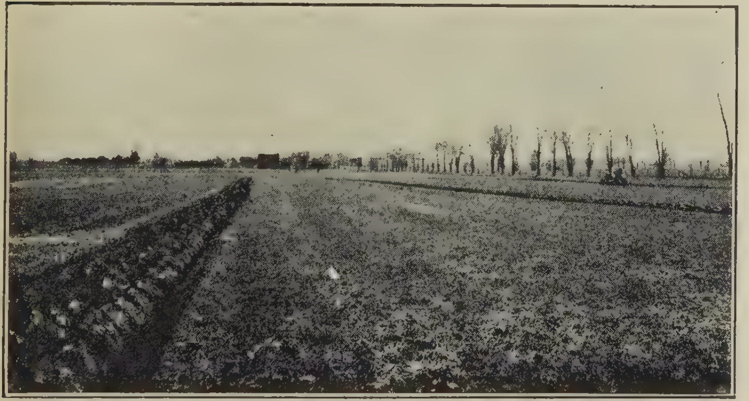

Fig. 87. Plan the Plowing.

In "striking out a land," that is, in plowing the furrows to mark out the strip, plow the furrows straight and exactly parallel.

the field for the next plowing, locate the strips in such a way that the back furrows occur where the dead furrows occurred in the previous plowing.

Do not plow when the soil is wet enough to be sticky. If the soil is too dry, the draft of the plow is increased and a heavy soil breaks up into clods. When heavy soils are extremely dry, it may be found impossible to plow them with the moldboard type of tractor plow. A soil may be either too wet or too dry for plowing.

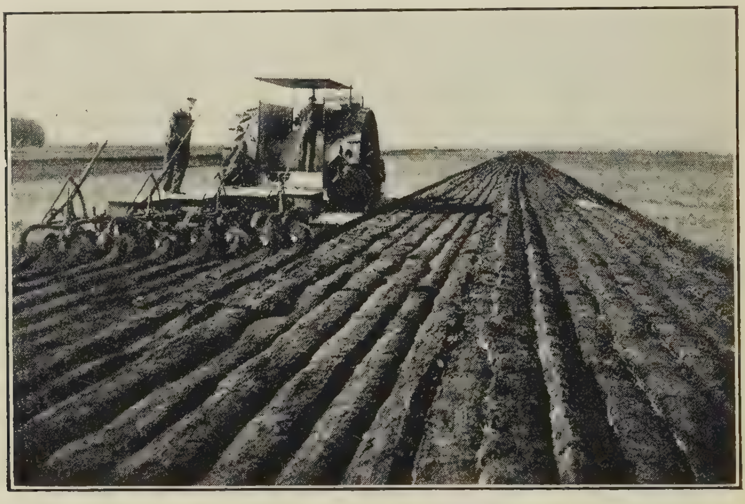

FIG. 88. PLOWING PRAIRIE SOD. (Agronomy Dept., Ill. Agr. Exp. Sta.)

A sloping moldboard may be used in plowing sod, though only under special conditions should the long flat moldboard, which entirely inverts the sod, be used.

The angle of the furrow slice is an important factor in plowing. Although this may be influenced somewhat by the set or adjustment of the plow, it is largely dependent, in moldboard plows, on the type or slope of the moldboard. A sloping moldboard may be used in plowing sod, though only under special conditions should the long flat moldboard, which entirely inverts the sod, be used. A more sloping moldboard is better for heavy soils than for friable or light ones. Use a plow that is adapted to the conditions encountered.[3]

To do a good job of plowing, the width of the furrow slice should be uniform. Its width will be determined by the size and set of the plow. One should never attempt to plow a wider furrow slice than the plow is made to handle; that is, do not adjust a 14-inch plow to cut a 15- or 16-inch furrow slice, for if this is done the outer zone of the slice will not be broken loose.

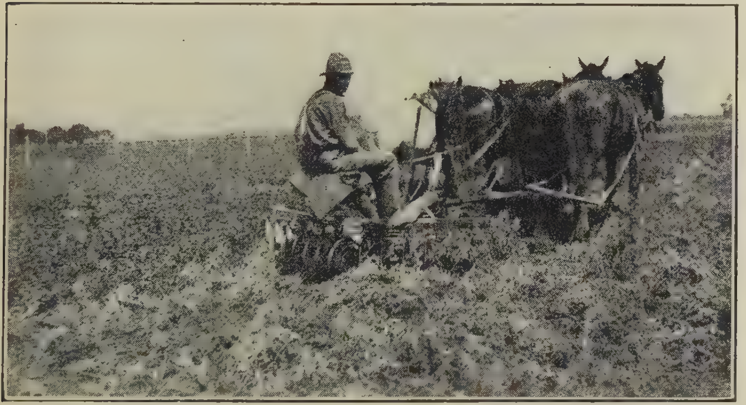

FIG. 89. DISKING A GREEN-MANURE CROP. (Agronomy Dept., Ill. Agr. Exp. Sta.)

As far as possible, disk a green-manure crop prior to turning it under.

Little can be done after plowing in breaking up the lower part of the seed-bed. Consequently, unless the condition of the soil is especially favorable at the time of plowing, the bottom part of the inverted furrow slice will not be properly broken apart. The practice of disking stubble land before plowing has been found helpful in this respect. If the land is too stony for disking, use the spring-tooth harrow before plowing. As far as possible, disk a green-manure crop prior to turning it under.

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[3] See General Information at end of chapter for types of moldboard plows.

**B. Plow at the proper time.** Plow when the soil contains the proper amount of water. With experience one readily learns the variation in moisture content of a given soil under which it can be plowed to advantage. A good way of testing a soil is to press a handful firmly together. If water can be forced out, it is too wet for plowing. Likewise, if a firm ball results from pressure, plowing should be delayed. When the compressed soil can be broken down into a mellow mass with the fingers, the moisture content is satisfactory. Sandy soils may be plowed with a relatively high- or low-moisture content, but clay soils have a narrower moisture range for plowing. In fall plowing in sections where soil freezes to the depth of plowing, a high-moisture content is not so objectionable since even a somewhat heavy soil is well granulated by freezing and thawing.

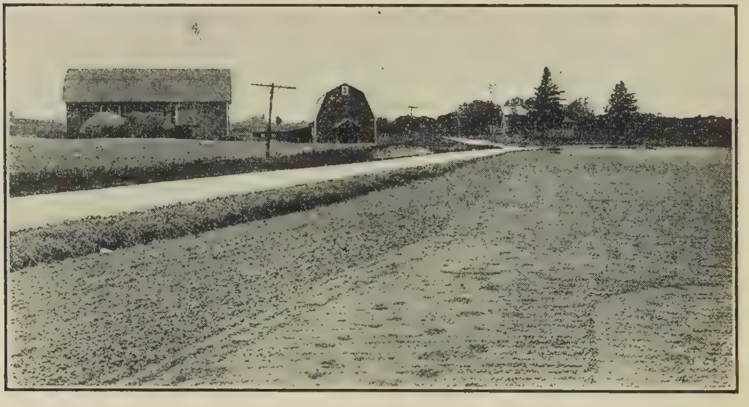

Fig. 90. A Well-Prepared Seed-Bed on Fall-Plowed Land.

**In sections where oats or wheat is grown as a spring crop, the plowing should be done in the fall if possible to facilitate early planting.**

Plowing is done in the spring or fall. Spring is the normal time for planting most farm crops. Seed-bed preparation most commonly starts with spring plowing. Farmers appreciate the importance of beginning the field work early in the spring and start plowing just as soon as the weather and soil conditions permit. In some sections considerable land is plowed in the late fall, and even during the winter months in the southern states. Fall plowing is ordinarily an indication of good soil management. In sections where oats or wheat is grown as a spring crop, the plowing should be done in the fall if possible to facilitate early planting. Although it is not so essential to fall-plow for corn and cotton as it is for oats and spring wheat, nevertheless the farmer who succeeds in plowing a large acreage in the fall is more certain of seeding the spring crops on time and in having a well-prepared seed-bed.

Sod land should generally be fall-plowed. The roots and stubble decompose during the late fall and early spring, so that by midsummer large amounts of plant-food, particularly nitrogen, become available for the growing crop, and good contact is reestablished between surface soil and subsoil. Where the topography is rough and the field subject to erosion, leave the sod as a protection over winter; or, if fall plowing is necessary, leave strips wide enough to prevent erosion, and plow them in the spring. In the southern states, where soil organic matter decomposes during the winter months, considerable nitrogen may be lost in the form of nitrates if sod is turned under in the fall. It is good practice never to have land bare through the winter months in sections where the surface does not remain frozen. Under such conditions, seed a winter cover crop on any land plowed in the fall.

In dry climates, fall plowing is beneficial in furnishing an increased water supply for the spring-seeded crops. It also aids in the control of certain insect pests and may be employed to advantage in weed eradication. Furthermore, where plowing is done with horses, they are in better condition in the fall than in the early spring. It is seldom that some fall plowing cannot be justified.

Do not fall-plow heavy clay soils that are subject to puddling. Late fall and early spring rains will pack and puddle the soil to such an extent that replowing may be necessary in the spring before a satisfactory seed-bed can be prepared. In the North, where the winters are cold and the soil subject to freezing and thawing in the spring, heavier soils may be fall-plowed than in the South, where winter conditions are more favorable for puddling and little or no granulation occurs. In fact, in the northern states where clay and clay-loam soils are well supplied with organic matter and not subject to puddling, fall plowing has invariably been found good practice.[4]

Spring plowing becomes of relatively greater importance where the winters are mild and the soil subject to constant leaching or where erosion or puddling may become serious on fall-plowed land. Livestock farmers frequently follow the practice of applying fresh manure to the corn ground during the winter months. Where it has been found best to plow this manure into the soil, it becomes necessary to leave the corn ground unplowed until spring. Where a clover or alfalfa sod is to be plowed for corn, potatoes, or some other cultivated crop, spring plowing may be justified on the ground that these legume crops make sufficient early growth prior to plowing to furnish worth-while amounts of nitrogen and organic matter.

In choosing between spring and fall plowing, consider all these factors from the standpoint of the individual farm. Determine the practices of the more successful farmers of the community. Plan to do some fall plowing unless conditions are such that spring plowing is definitely preferable. If land is plowed in the fall, leave it over winter in the rough, that is, unharrowed until spring. It will be less subject to erosion and more capable of maximum moisture absorption. Snow will be held more efficiently and the maximum benefit from freezing and thawing secured. Nothing is to be gained by harrowing or dragging fall-plowed land until the following spring, unless a fall application of lime is made, and then the lime should be worked into the topsoil immediately after application.

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[4] See Chapter I, Soil Granulation.

For winter grain, such as wheat, plow as early as possible. A firm seed-bed has been found most essential for this crop. When the plowing is necessarily delayed, the field should be thoroughly rolled several times with some type of corrugated roller before the crop is seeded. Winter injury to wheat will be reduced if it is seeded on a well-compacted seed-bed.

**C. Plow to the proper depth.** Six to 8 inches is a good depth for plowing. For some crops, such as wheat and rye, 5 to 6 inches may be sufficient; for others, such as potatoes, when soil conditions are right, plowing to a depth of 9 or 10 inches may be justified. In sections of low rainfall, land may be plowed deeper than in the humid regions. Plowing to a depth of 12 to 14 inches is advocated in certain of the western states. In the East and South, 6 to 7 inches is a common depth of plowing; in the prairie soils of the Central West, fully 7 inches is desirable for corn.

A great many factors influence the depth of plowing. A deep seed-bed is desirable for most crops. True surface soils are generally less than a foot and frequently not more than 6 to 8 inches deep. As a rule, plowing should be confined to the surface soil. Where the surface has a depth of less than 7 inches, it is necessary to plow into the subsoil if a 7-inch seed-bed is required. When this is done, the depth should be increased gradually, for if any material amount of "raw" subsoil is thrown up in a single season, crop injury will result.

Subsoil plowing consists of loosening up the subsoil to a depth of 6 to 10 inches without throwing it to the surface. The subsoil plow follows in the furrow back of the regular breaking plow. Dynamite is sometimes used for breaking up impervious subsoils. Subsoil tillage, though often beneficial, is seldom profitable. It is not a practice to be followed except in special sections of the semi-arid West.

The depth of plowing should be varied somewhat from year to year. The moldboard plow tends to compact the soil at the bottom of the furrow as does the pressure from the horses' feet or tractor wheel. Such a compact layer is known as a *plow-sole,* and may become so compact as to interfere with the movement of soil water.

All crops do not have the same requirement for depth of seed-bed. Corn, for example, does best when the seed-bed is deep and mellow, whereas the small grains, particularly winter wheat, need a relatively shallow but firm seed-bed. Consequently, one should plow to the depth best suited to the crop to be planted.

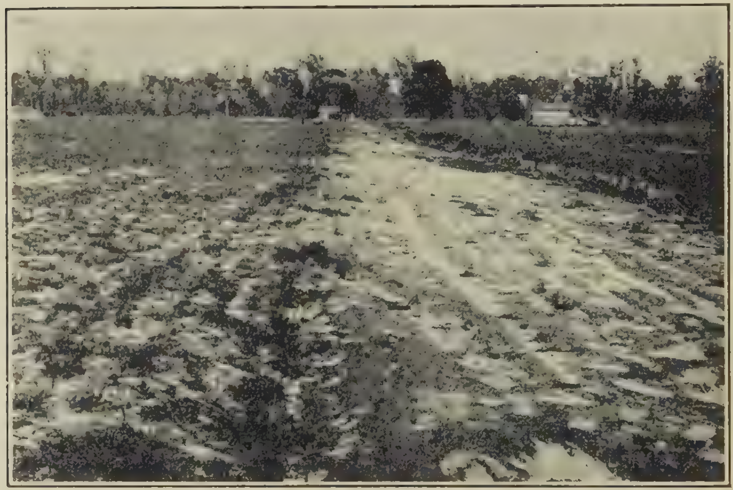

FIG. 91. INJURY CAUSED BY DEEP PLOWING.

If any material amount of "raw" subsoil is thrown up in a single season, crop injury will result.

Another important factor in determining the depth to plow is the cost. For every additional inch of depth there is a rapid increase in the amount of power required for plowing. Irrespective of the source of power, increased depth means additional expense. Consider this factor before deciding on a depth in excess of 7 inches.

Except in dry sections, 7-inch plowing gives satisfactory results. Occasionally 8 inches may be justified, and sometimes 6 inches will suffice. It is well to take a ruler and actually measure the depth of the furrow when starting to plow. Make the measurement on the unplowed side, called the *land side*, of the furrow. The depth of plowing invariably seems greater than it proves to be on measuring, and in practice it is more often too shallow than too deep.

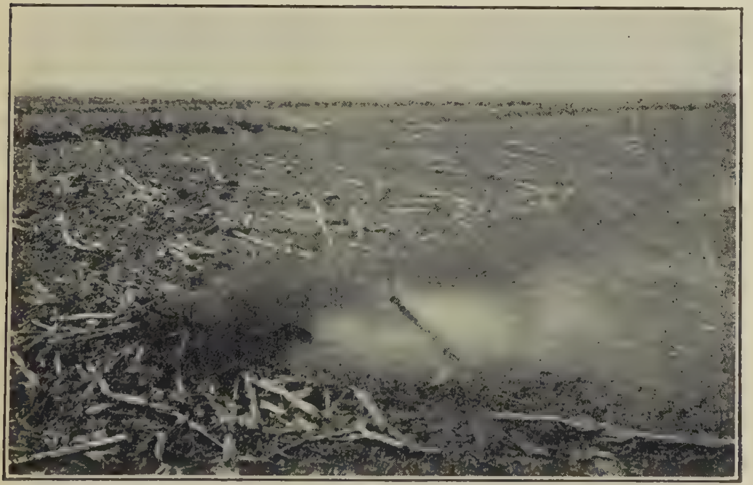

FIG. 92. BURNING CORNSTALKS. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Cornstalks and cotton stalks, as well as straw, are often burned in the field. This wasteful practice, favoring soil depletion, can be justified only when necessary for the control of disease or insect pests.

**D. Plow under organic matter.** It is by means of plowing that additional organic matter is incorporated with the soil. Farm manure, green-manure crops, sods, stubble, weeds, and crop residues, such as straw, corn stover, cotton stalks, and the like, are the materials used for replenishing the soil supply of organic matter. Unfortunately because of the difficulty of plowing them under, cornstalks and cotton stalks, as well as straw, are often burned in the field. This wasteful practice, favoring soil depletion, can be justified only when necessary for the control of disease or insect pests. An excellent means of control of the corn borer, so troublesome in many sections, is the plowing under of the stalks or the stubble in the fall.

Where a heavy growth of weeds or of a green-manure crop is to be turned under, use a drag chain on the plow to facilitate covering the plants. In the grain section, use a straw distributor for returning the residue of the small-grain crops. In livestock sections, utilize straw as feed and bedding in order that it may be returned to the soil in the farm manure. Corn stover, as well as straw, should be utilized as feed and bedding by livestock farmers. Grain farmers should return it directly to the land. Where cornstalks or cotton stalks are to be plowed under, a field stalk cutter can be used to advantage.

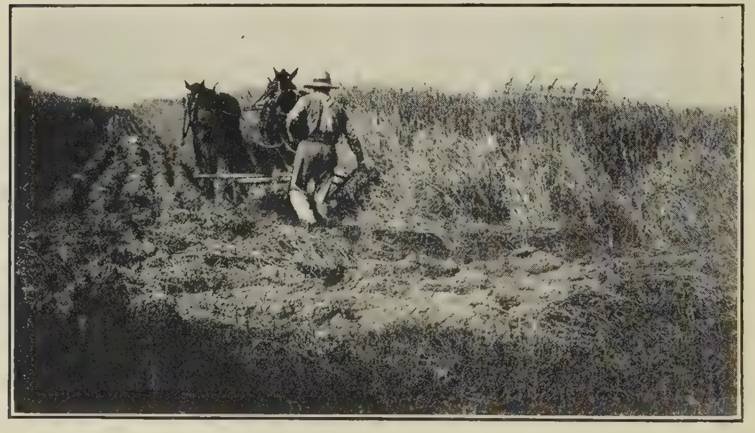

Fig. 93. Plowing under Green Manure.

When organic matter is plowed under, do not turn the furrow slice completely over.

When organic matter is plowed under, do not turn the furrow slice completely over. If this is done, the organic matter forms a more or less continuous layer at the base of the seed-bed, which may interfere with the normal movement of the soil moisture during the cropping season. Edge up the furrows at a good angle, even though some of the organic material may not be completely covered. Plow organic matter into, rather than under, the surface soil.

**E. Care for the plow.** The plow, like other machinery of the farm, requires care. Although it is not so susceptible to depreciation from exposure as some other implements, it should not be left in the field from season to season. Keep the plowshare or point sharp at all times, and replace when worn.[5] When the plow is not in use, apply heavy grease to all polished surfaces to prevent rusting. If this is done, the soil will not adhere to the plow when used again. The plow is then said to scour properly. Other tillage machinery is equally deserving of good care. Its life, as well as its efficiency, will be enhanced by giving it proper attention.

Proper adjustment of the clevis, as well as of the jointer or the coulter, is essential. Care in this detail will not only improve the quality of the plowing but may materially lessen the draft of the plow and increase the ease with which the plowing can be done. Adjust the plow in accordance with specifications.[6]

## 2. Preparing the Seed-Bed

Plowing does not produce a finished seed-bed. It merely prepares the soil for the tillage operations constituting real seed-bed preparation. The effectiveness of these operations is dependent to a large extent on how well the plowing has been done.

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[5] See General Information at end of chapter for discussion of plow parts.

[6] See General Information at end of chapter for adjustment of plow parts.

**Procedure:**

A. Harrow.
B. Disk.
C. Roll.
D. Give the proper amount of preparation.

**A. Harrow.** Harrowing or disking is generally the first operation in seed-bed preparation after the land is plowed. In spring plowing, harrow the land the same day it is plowed. If the plowed soil is permitted to dry without being harrowed, it may be necessary to wait for a rain before effective harrowing can be done. In dry sections where the prevention of wind erosion is a problem, seed-bed preparation should be delayed until just before planting. Proper moisture content of the soil is as essential in fitting the seed-bed as it is for good plowing. Never work the soil when it is wet, particularly if it has a high clay content.[7]

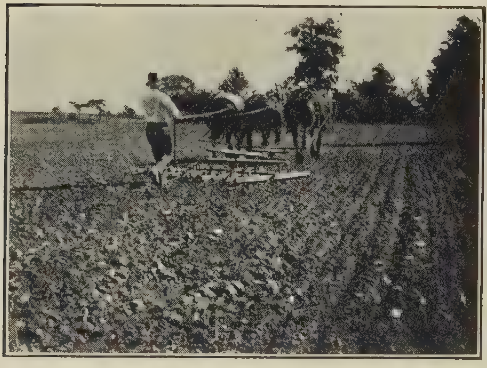

FIG. 94. HARROWING. (Agronomy Dept., N. Y. State Col. of Agr.)

Harrowing or disking is generally the first operation in seed-bed preparation after the land is plowed.

Two harrowings are generally necessary. Less preparation should be given in arid than in humid sections on account of injury by wind erosion. Where the seed-bed preparation is done entirely with the spring-tooth and drag-type of harrows, go over the plowed land at least three times. Harrow crosswise of the furrows the first time over the field except where sod has been plowed down. Each additional harrowing should be crosswise of the previous one. If soils are very stony in character, the spring-tooth harrow may prove not only the most efficient implement but also the only practical one to use in the preparation of the seed-bed. It is seldom, however, that some other implement cannot be used to advantage. In fact, it is unusual to find a really good seed-bed resulting from harrowing alone.

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[7] See General Information at end of chapter for types of harrows, disks, and rollers.

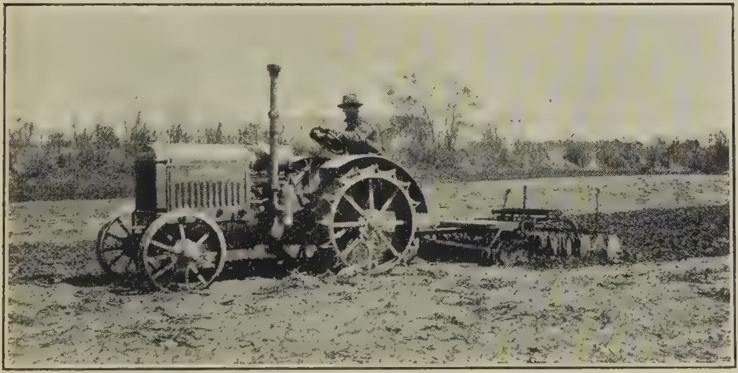

FIG. 95. DISKING. (International Harvester Co.)

The disk is of great value in working up fall-plowed land in the spring.

**B. Disk.** The disk is a most valuable implement for fitting soils. It should be run with, and not crosswise of, the furrows. It cuts down well into the plowed soil and is most effective in fining the soil to a depth of several inches. It is adapted to both heavy and light soils, but its use is less effective where the surface soil is stony. When combined with one of the common types of tooth harrows, the disk does very efficient work. Frequently a satisfactory seed-bed can be prepared by disking the land several times instead of plowing. This practice is particularly successful where a fall-seeded crop, such as wheat, follows a cultivated crop, such as corn, potatoes, or beans. If the soil is naturally friable in character and free from stone, a satisfactory seed-bed may be prepared for most crops by disking instead of plowing. The heavy tractor disk facilitates seed-bed preparation without plowing. Where manure is plowed under for corn, and the oat ground seeded down, fewer weeds will appear in the hay crop if the land is disked for oats because the manure and any weed seed which it contains remain covered.

The disk is of great value in working up fall-plowed land in the spring. Fall plowing would be impracticable on some soils unless a disk could be used for seed-bed preparation in the spring. It is also useful in working over a cover crop prior to plowing it under as green manure. The disk is a most satisfactory implement to use in loosening the topsoil before plowing in order to give proper preparation to the lower section of the seed-bed. Few farms can afford to do without this modern tillage implement.

**C. Roll.** Both the disk and the tooth harrows tend to loosen rather than compact the seed-bed. Some means must be provided for firming the plowed soil, especially if it is sandy in character. Land that is fall-plowed settles during the winter and early spring, resulting in a firm seed-bed; but if land is plowed just prior to planting, it should be rolled thoroughly to firm the soil. Though of value in this particular, rolling can never equal fall plowing in producing a firm seed-bed.

Use a corrugated-type roller such as the cultipacker in preference to the smooth-type roller. The seed-bed will be firmed, and at the same time the surface will be left in a fairly loose condition, and as a result a crust will be less likely to form on the surface. The practice of rolling immediately after the seeding of the small-grain crops is desirable in many sections, but injury sometimes results to both the grain and the accompanying grass crop where a smooth roller is used and weather conditions are favorable to the formation of a crust. This objection to the smooth roller may be overcome by following it with the drag harrow, but the additional operation adds to the expense. Where small grain is seeded during a dry season, or on very sandy soils, the rolling may facilitate germination owing to the rise of soil water in a well-rolled soil.

Where mineral soils are subject to blowing, rolling may increase the injury, but with muck and peat soils rolling may prevent the surface from drying and thereby reduce wind erosion. Meadows and permanent pastures should be rolled in the early spring when the soil is still soft if the plants have heaved as the result of alternate freezing and thawing. The roller, as well as the plank drag, is useful in breaking clods. When used in combination with the harrow and disk, it aids materially in developing the proper tilth of the seed-bed.

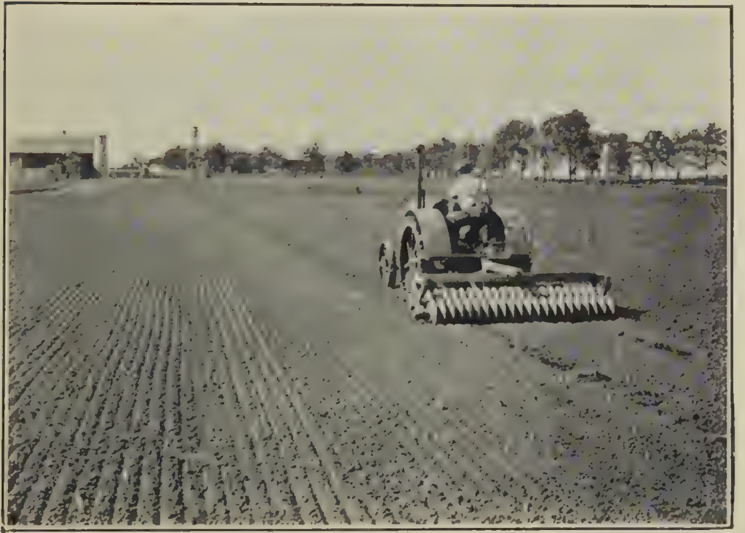

FIG. 96. ROLLING WITH A CULTIPACKER. (International Harvester Co.)

**Use a corrugated-type roller such as the cultipacker in preference to the smooth type of roller.**

**D. Give the proper amount of preparation.** The amount of tillage necessary for the preparation of an adequate seed-bed will naturally vary under different circumstances. The character of the soil is an important factor, as is also the degree of infestation of weeds and the susceptibility of the soil to wind erosion. A single harrowing of a friable sandy loam may be more effective than several workings of a clay soil.

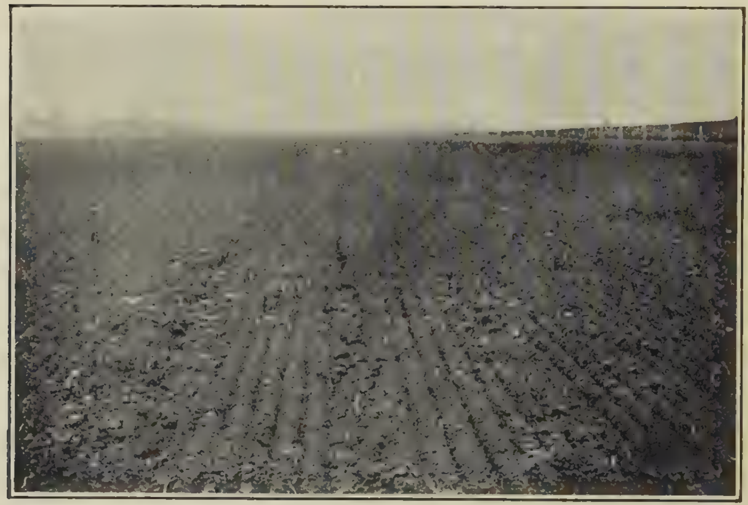

FIG. 97. A WELL-PREPARED SEED-BED. (Agronomy Dept., Ill. Agr. Exp. Sta.)

**If time will permit, go over the plowed field three to four times before planting.**

Besides texture and weed control, the moisture and organic-matter content of the soil are also influencing factors, and stones occurring in large numbers in the surface soil may interfere with efficient seed-bed preparation. If time permits, any reasonable amount of labor necessary for the development of a first-class seed-bed free from weeds is justified. It has been aptly said that the best time to cultivate a crop is before it is planted. It is certainly true that no amount of cultivation given the growing crop will entirely make up for a poorly prepared seed-bed.

In practical field-crop production, economy in seed-bed preparation, as in the other operations, is essential. Though a poorly prepared seed-bed cannot be justified on the grounds of economy, nevertheless labor should not be expended after the soil is in satisfactory condition to receive the seed. Efficiency should be secured through the choice of the proper implements and by making certain that they are used effectively.

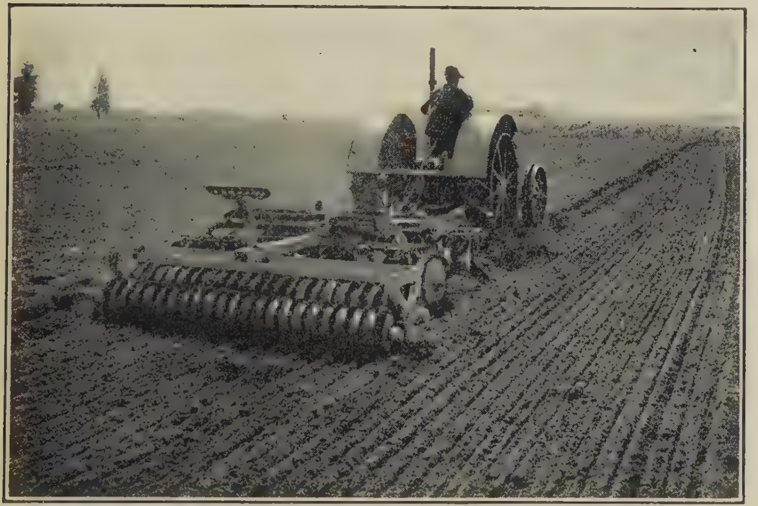

FIG. 98. PREPARING THE SEED-BED. (International Harvester Co.)

Satisfactory seed-beds have been secured by combining the double disk and double cultipacker.

With a friable, sandy-loam soil, two harrowings may produce a fair seed-bed. In addition, rolling is desirable and should prove profitable. Even under the most favorable conditions, the minimum preparation would be two harrowings. Going over the field once with a double disk, followed by a smoothing harrow, will sometimes put the soil in fair condition for seeding. More often, even if disked, the soil needs two harrowings. If time will permit, go over the plowed field three or four times before planting. First disk, then roll, and finally harrow at least once and preferably twice. If a tractor is used, the harrow may be hitched on behind the disk for the first operation and then back of the roller the second time, so that twice over the field will give the four operations. Satisfactory seed-beds have been secured by combining the double disk and double cultipacker. Most tractors will handle the two implements satisfactorily on level land.

After all, judgment and experience must largely be depended upon in determining the amount of time that should be expended in the preparation of the seed-bed. For best results crops should be seeded on time. The date of planting cannot be delayed too long in order to secure a perfect seed-bed. There is a point beyond which additional expense in soil preparation will not return a profit. Although it is true, then, that a good seed-bed is essential for the normal development of the crop and that the final yield will be largely dependent on the nourishment secured from the plowed soil, nevertheless there is a limit beyond which seed-bed preparation becomes impracticable.

## 3. Cultivating the Crop

Such crops as small grain and hay are seeded so thickly on the land that tillage after planting is not normally required. When a good stand is secured, weeds are effectively crowded out. In fact, thorough cultivation is impracticable because of possible injury to the crop itself. Other crops, such as corn, cotton, and potatoes, are grown in rows several feet apart. They are known as *hoed* or *cultivated crops*. The soil between the rows in the early stages of crop growth must be kept stirred in order to keep down weeds, and, in dry climates at least, to conserve soil moisture. Tilling between the rows is commonly spoken of as *cultivation*.

**Procedure:**

A. Cultivate to kill weeds.
B. Practice shallow and level cultivation.
C. Determine frequency of cultivation.

**A. Cultivate to kill weeds.** The primary purpose of cultivation is to kill weeds. When permitted to grow, weeds compete with the crop for food, water, and sunlight. Few soils are sufficiently fertile to supply an adequate amount of plant-food for the maximum growth of crops, even when weeds are not competing for the available supply. Neither is the moisture supply sufficient throughout the season for both crop and weeds. With slow-growing crops, weeds may cause serious injury and in fact crop failure, because of shading. The successful production of practically all crops necessitates adequate weed control.[8]

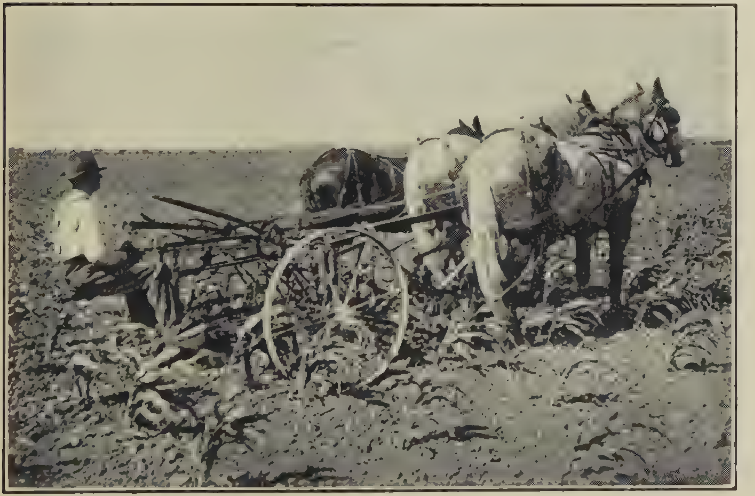

FIG. 99. CULTIVATING CORN. (Farm Mechanics Dept., Ill. Agr. Exp. Sta.)

The primary purpose of cultivation is to kill weeds.

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[8] See Chapter II for essentials of plant growth.

Even though much can be accomplished in the control of weeds through proper tillage before the crop is planted, there is always need for additional attention soon after planting. Needless to say, the best time to kill weeds is while they are small. It has been found practicable to harrow corn, potatoes, soybeans, and some other rowed crops with a drag harrow or weeder until they are several inches high. During this early stage of growth, little injury is done to the plants, but many weeds less securely anchored in the soil are destroyed.

When the crops reach a height of several inches and the rows are easily discernible, the row cultivator should be used.[9] With it, weeds can be kept down between the rows. Where crops are produced intensively, the removal of weeds from the row by hand hoeing, or pulling, is often practicable. In the field production of crops, these weeds can be partly kept down by adjusting the cultivator so that a small amount of soil will be thrown to the row from either side. In "chopping," that is, thinning, young cotton with a hoe, some weeds that have started in the row are killed. By planting such crops as corn and potatoes in hills, cultivation can be done in both directions, and weeds can be more economically controlled than where these crops are planted in rows.

The secret of successful cultivation is never to permit weeds to get a good start. Where practicable, give the weed seed an opportunity to germinate in the surface of the plowed soil before completing the preparation of the seed-bed, then destroy the young weeds by disking or harrowing. Go over the field once or twice with a weeder or drag harrow with the teeth set back at an angle of 15 to 30 degrees. If a crust should form before the crop is up, a light harrowing of this kind will break the crust and enable the young plant to push through the surface. When this preliminary tillage is efficiently done, weeds can be more easily controlled through row cultivation.

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[9] See General Information at end of chapter for types of cultivators.

It was thought at one time that the conservation of soil moisture was the chief benefit of cultivation. Now it is generally conceded that moisture conservation is of secondary importance to the destruction of weeds. The value of the soil mulch was greatly exaggerated for a number of years. While it lessens the evaporation of soil water, it also lessens the amount of surface soil available for the development of plant roots. It is in the drier climates that the soil mulch is most beneficial. It has also been found that water conservation by means of stirring the surface is more essential with a clay or clay-loam soil than with one of lighter texture. Likewise, a high organic-matter content of the surface soil will act as a natural mulch, and reduce the necessity of cultivation as a means of conserving moisture.

The value of tillage in general as a means of water conservation is not dependent primarily on the maintenance of a soil mulch by cultivation. Nevertheless, the control of weeds requires the stirring of the topsoil; and, even though under some conditions the expense incurred could not be justified from the standpoint of moisture conservation, this is a secondary benefit of cultivation which should not be overlooked. In sections of moderately heavy rainfall during the summer months, cultivation should be no more frequent and no deeper than necessary for the control of weeds.

**B. Practice shallow and level cultivation.** Level cultivation to a shallow depth gives best results except in very dry sections. Corn grown on black prairie soils yields more if the weeds are hoed out than if the crop is thoroughly cultivated to a depth of several inches. This does not mean that hand hoeing should replace cultivation, but rather that in cultivating corn the soil should be stirred no more deeply than is necessary to kill the weeds.

The objection to deep cultivation is that it reduces the area of surface soil in which the crop roots may develop. The plant-food is largely secured from the true surface soil, and to reduce the volume available to the root system cuts down the food supply of the growing plant. Also, the roots develop to some extent in the upper soil between cultivations, and are injured, if not entirely cut off, by continued deep cultivation. It is less injurious to cultivate deeply when the crop is small than it is later in the season when the root system has extended well out through the soil between the rows. Even in early cultivation, nothing will be gained by going deeper than is absolutely necessary to kill weeds.

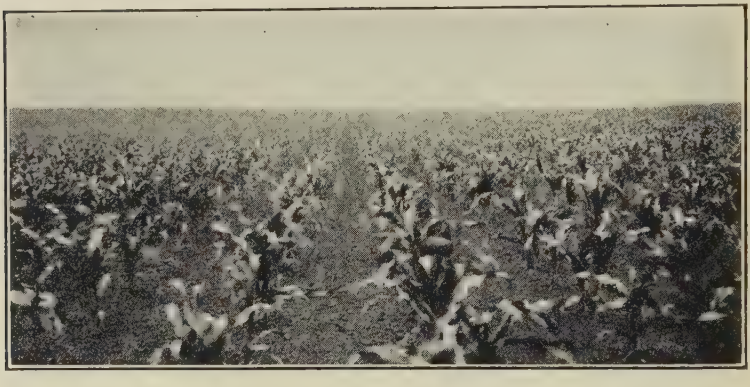

FIG. 100. A WELL-CULTIVATED FIELD OF CORN. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Level cultivation to a shallow depth gives best results except in very dry sections.

Level cultivation has become almost a universal practice within recent years. Ridging necessitates deep plowing between the rows. Crops are seldom benefited by deepening the surface soil in the row at the expense of that between rows. A small amount of soil may be thrown to the row where necessary to cover weeds. In some soils ridging of potatoes is advisable. In general, however, practice level cultivation and under no conditions follow the old type of high ridging.

**C. Determine frequency of cultivation.** The frequency of cultivation, like the depth, is dependent largely on weed control. The cultivation of field crops can seldom be justified, except possibly in dry sections, unless necessary to kill weeds. At one time farmers were advised to cultivate after every rain and to continue cultivating as long as a horse could be driven between the rows. The soil-mulch idea was carried to such an extreme in some instances that old mowing-machine wheels and other cultivator substitutes were dragged between the rows of corn and cotton to produce what was frequently termed a *dust mulch*. Economy in field-crop production has emphasized the necessity of abandoning unprofitable tillage operations. Efficiency, rather than frequency, should be the objective in cultivation. If weeds are properly controlled prior to and immediately following planting, three cultivations will generally suffice. Seldom can more than four cultivations be justified for such crops as corn and cotton. Preliminary tillage operations should obviate any need for additional intertillage of the growing crop.

The practice of rolling or harrowing small-grain and hay crops can well be considered a type of cultivation. Beneficial results often follow the rolling of winter wheat in the early spring, particularly where root injury has resulted from winter heaving. The corrugated type of roller should be used for spring-rolling of winter wheat. Solid plantings of certain crops such as soybeans should be harrowed once or twice after they have started growth.

Where clover or alfalfa is seeded on wheat in the spring, it is a good practice to go over the field immediately afterward with a harrow or weeder. Clover and alfalfa fields, as well as permanent pastures, are frequently rolled in the early spring. The firming of the soil around the plants at this season is beneficial. Old alfalfa fields are sometimes disked, but the opinion of better alfalfa growers is that the practice is unprofitable.

## GENERAL INFORMATION

### 1. Benefits of Tillage

The benefits of tillage may be summed up as follows:

(1) It produces a favorable tilth or soil structure for the development of roots, thereby increasing the available feeding area for the plant.

(2) It improves the aeration of the soil, resulting in increased bacterial and chemical activity which in turn increases the amount of available plant-food in the soil.

(3) It conserves moisture by reducing surface runoff, lessens evaporation of water from the surface, and reduces the actual water requirement of the plant on the basis of dry matter produced.

(4) It kills weeds and thereby conserves both plant-food and water for the plants.

(5) It helps in the control of certain insects and plant diseases.

(6) It makes possible the incorporation of organic matter with the soil.

(7) It puts the soil into condition for receiving the seed. As a result of rolling, moisture may rise from below in sufficient amounts to germinate the seed promptly after planting.

(8) Rolling of hay and pasture sods, as well as of winter grain, in the early spring reduces winter injury.

### 2. Tillage Implements

**A. Types of plows.** The modern plow is the result of slow development through the generations from the forked stick of the ancient farmer. Wooden plows were in universal use prior to and immediately following the Revolutionary War. They were protected to some extent by strips of iron nailed to the parts most subject to wear. Cast-iron plows were first made in the later years of the eighteenth century, but it was not until well into the last century that the metal plow was used extensively.

The modern steel plow with its replaceable parts was developed about the time of the Civil War. The wooden as well as the metal plows were of the moldboard type. From them, the modern moldboard plow was evolved. Today it is in almost universal use throughout the country whether in the form of the one-, two-, or three-horse plow, or combined into four-horse gangs, or even larger tractor gangs. The walking plow is still in common use in many sections, though the sulky or riding plow has become very popular. The tractor is being used more extensively each season as a source of power for plowing.

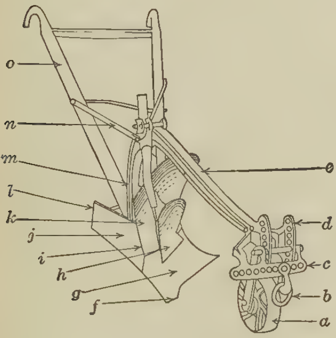

FIG. 101.

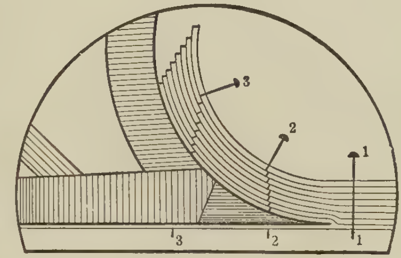

FIG. 102.

FIG. 101. PLOW PARTS.

*a.* gauge wheel
*b.* hitch clevis
*c.* beam clevis
*d.* bridle
*e.* beam
*f.* point
*g.* share
*h.* jointer
*i.* shin
*j.* landslide
*k.* moldboard
*l.* heel
*m.* standard
*n.* brace rod
*o.* handle

FIG. 102. CRUMBLING EFFECT OF MOLDBOARD PLOWS. (After King.)

The effectiveness of the moldboard plow depends on the slope or curve of the moldboard. As the furrow slice slides up the curved moldboard, it tends to separate into thin layers. Note breaking of pin—1, 2, and 3.

The moldboard plow has five essential parts: (1) the share, or point, which cuts the furrow slice from the soil below; (2) the moldboard, which lifts and partly inverts the furrow slice, pulverizing it to some extent at the same time; (3) the landslide, which follows along the vertical edge of the furrow and holds the plow in place; (4) the beam, to which the plow proper is attached by means of a standard and to which the handles are fastened at the rear; and (5) the clevis, or hitch, attached to the front end of the beam, which can be so adjusted as to vary both the width and thickness of the furrow slice. For the plow to do its most effective work, either a jointer or a coulter should be attached to the plow beam for cutting the upper edge of the furrow slice or for loosening somewhat the upper soil before it is turned under. The jointer is in reality a small plow, while the coulter is a knife or a rotary disk which cuts through the soil to the depth of an inch or more. These plow parts are shown in Fig. 101. Either the coulter or the jointer should be used in plowing sod. In stony soil the jointer is the better; under other conditions the coulter is in more common use. Sometimes they are used together, the coulter being attached to the beam in front of the jointer. The use of the jointer is desirable also in plowing stubble land.

The effectiveness of the moldboard plow depends on the slope or curve of the moldboard. As the furrow slice slides up the curved moldboard, it tends to separate into thin layers. The breaking or crumbling effect is illustrated by Fig. 102; it can also be clearly demonstrated by bending the leaves of a book to conform to the curve of a moldboard. Obviously, the steeper the moldboard the greater is the crumbling effect on the furrow slice.

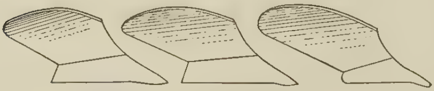

FIG. 103. THREE MAIN TYPES OF MOLDBOARD PLOWS.

There are three main types of moldboard plows: stubble plow, general-purpose plow, and sod plow. The first is sometimes called a fallowland plow, and the third a breaking or a turf plow.

There are three main types of moldboard plows: (1) the *stubble plow*, (2) the *general-purpose plow*, and (3) the *sod*

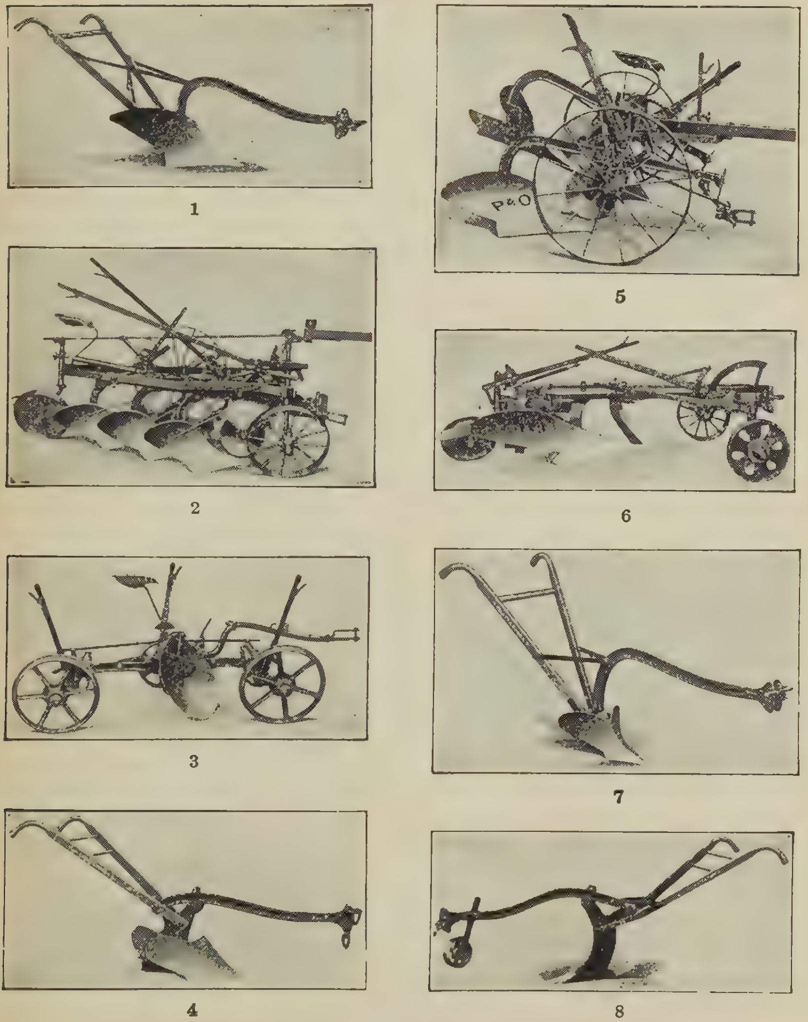

FIG. 104. TYPES OF PLOWS. (International Harvester Co.)

1. Walking plow.
2. Gang plow.
3. Disk plow.
4. Swivel plow.
5. Two-way plow.
6. Prairie breaker.
7. Middle buster.
8. Subsoil plow.

*plow.* The first is sometimes called a fallowland plow, and the third, a breaking or turf plow. The difference, as can be seen in Fig. 103, is the shape of the moldboard. The lister and middle buster (Fig. 104), having double moldboards which open up a dead furrow, might be considered a fourth type. The lister is used in the West when planting is done in the depressions between backfurrows, and the middle buster in the South where crops such as cotton are frequently planted on narrow parallel beds. The prairie breaker (Figs. 88 and 104) is a sod plow with an extremely long, sloping moldboard that completely inverts the furrow slice.

Good plowing necessitates the selection of a plow adapted to the conditions at hand. The general-purpose plow is most extensively used for breaking land, though it should be replaced by either the sod or the stubble plow under conditions where they would be more effective. The sod plow, with its longer and less sloping moldboard, is best adapted, as the name implies, to the plowing of sod ground. It should not be used except where considerable vegetation is to be plowed under. Thin sods can be efficiently plowed with the general-purpose type. For heavy soils a steep moldboard should be used as far as possible, since it has a greater crumbling effect. If it becomes necessary to plow a soil when wet, the more sloping moldboard is preferable because it will puddle the soil less.

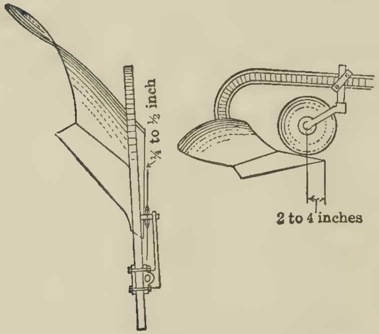

FIG. 105. ADJUSTMENT OF WHEEL COULTER.

A wheel coulter requires more exact adjustment than the jointer.

In plowing hillside fields, the slope may be so steep that the furrow slices cannot be thrown uphill. The draft would be too great for uphill and downhill plowing, and dead furrows left by such plowing might be the cause of serious gully erosion. The hillside plow has been devised for such conditions.

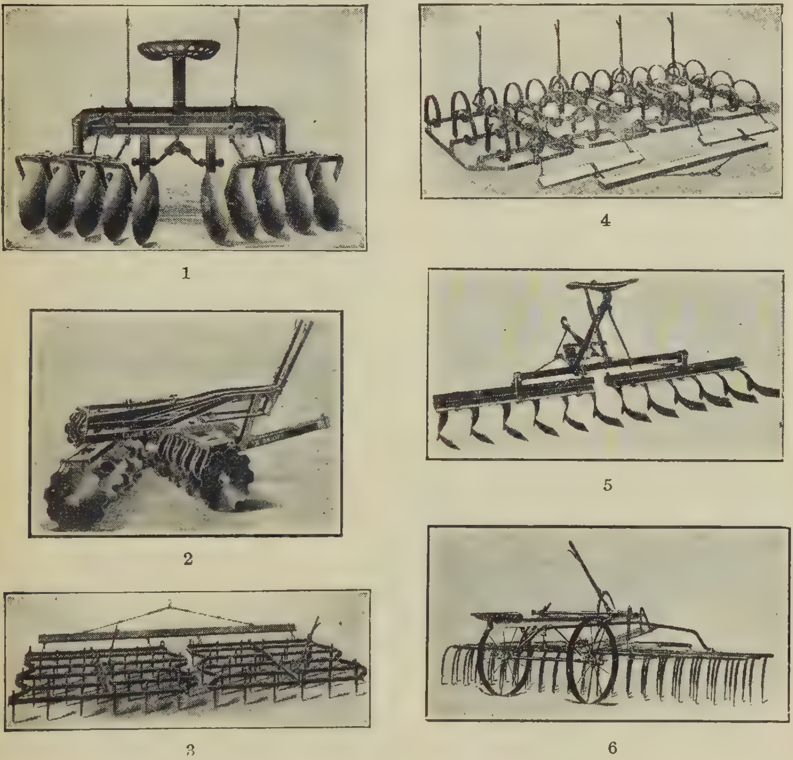

Fig. 106. Types of Harrows.

1. Smooth disk.
2. Cutaway disk.
3. Smoothing or spike-tooth harrow.
4. Spring-tooth harrow.
5. Acme harrow.
6. Weeder.

(1, 3, 4, and 6, International Harvester Co.)
(2, The Cutaway Harrow Co.)
(5, Nash-Acme Harrow Co.)

It is so constructed that the furrow slice can be thrown in either direction, and consequently, by starting at the lower side of a sloping field, all furrow slices are thrown downhill, and dead furrows and backfurrows are obviated. Where slopes are not too steep, furrows should be thrown uphill rather than downhill. With such an implement, contour plowing may be done most effectively. It is also well adapted to the plowing of small, irregularly shaped fields.

There are two distinct types of hillside plows, or plows with which furrows may be opened up either to the right or to the left. The reversible or swivel plow is so constructed that the moldboard can be shifted from side to side. The other type, known as the two-way plow, consists of two plows, one throwing the furrow slice to the right and the other to the left, mounted on a single frame and each capable of being raised or lowered. By alternating the two plows, furrow slices may be thrown in one direction.

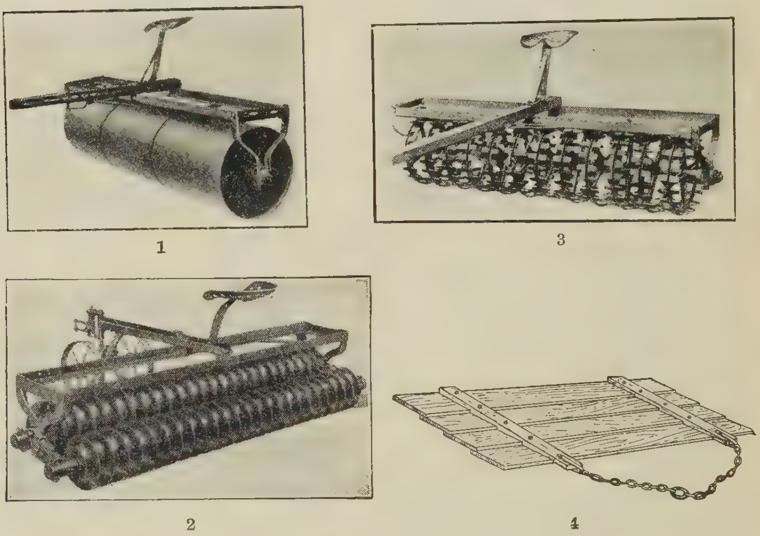

Fig. 107. Types of Rollers and Drags.

1. Smooth roller.
2. Cultipacker.
3. Crowfoot roller.
4. Plank drag.

(1 and 3, Agronomy Dept., Ill. Agr. Exp. Sta.)
(2, International Harvester Co.)

The disk plow is not in common use. It is best adapted to soils in which the moldboard plow will not scour properly. It cannot be used advantageously in a stony soil. Its use is, and should be, restricted to soil conditions in which the moldboard plow is ineffective.

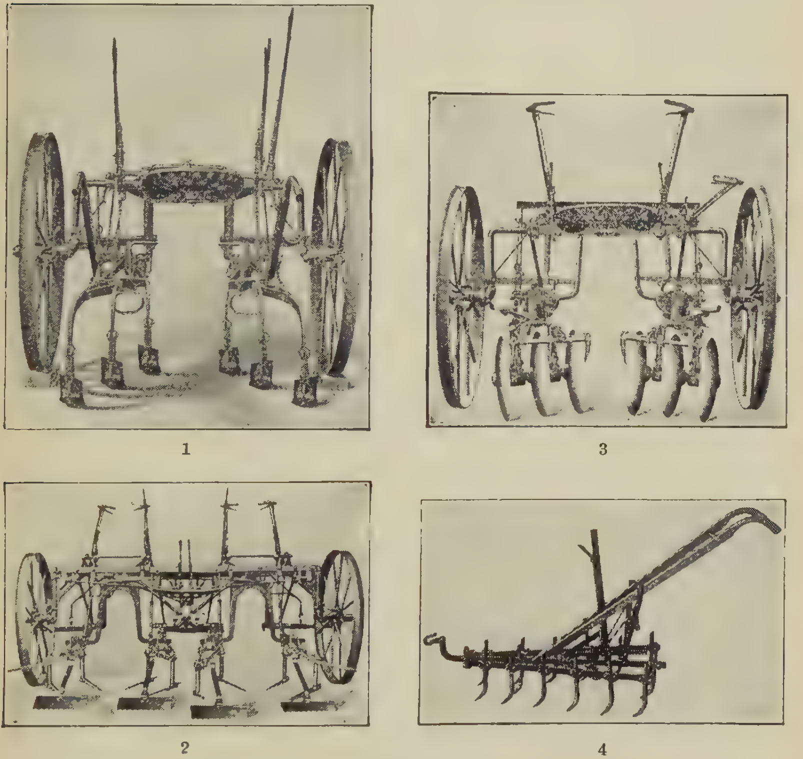

Fig. 108. Types of Cultivators. (International Harvester Co.)

1. Shovel cultivator.
2. Blade cultivator.
3. Disk cultivator.
4. Tooth cultivator.

The subsoil plow consists of a metal shoe fastened to the end of a strong bar extending down from a horizontal beam. In subsoiling this shoe is forced into the subsoil and pulled through it at a depth of 12 to 18 inches below the surface of the ground. (See Fig. 104.)

**B. Adjustment of plow parts.** Various adjustments must be made if effective plowing is to be accomplished. First, the proper hitch to the clevis must be made. This will vary with the depth of plowing: the deeper the plowing the higher should be the hitch. If a beam clevis is used, shift the hitch either to the right or to the left for adjusting the width of furrow slice. If a gauge wheel is used, adjust up or down to conform to the depth adjustment made in the clevis. If a jointer is used, adjust so it will cut 2 to 3 inches deep. A wheel coulter requires more exact adjustment. Clamp it to the beam so that the axis of the wheel will be about 3 inches to the rear of the plow point, for ordinary soil. One or 2 inches will suffice in sandy soil; in clay, the distance should be increased to 4 inches. (See Fig. 105.) Before clamping the coulter to the beam, adjust sidewise, allowing about ½ inch between it and the land side of the plow. For sod ground or for very deep plowing, reduce this distance to ⅓ or even ¼ inch. (See Fig. 105.)

**C. Types of disks and harrows.** The more common types of disks and harrows are shown in Fig. 106. The double, smooth-type disk and the spring-tooth and the drag or spike-tooth harrows are the types most extensively used. The rotary hoe is gaining in popularity in many sections.

**D. Types of rollers and drags.** Figure 107 includes the more common rollers and drags. The roller and the common plank drag have been found most excellent implements for compacting the seed-bed and for crushing clods.

**E. Types of cultivators.** In Fig. 108 the common types of cultivators are illustrated. Shovels, knives, or disks are used for stirring the soil. The type that will kill weeds effectively without stirring the soil to any great depth will be found best. The effectiveness of the cultivator will depend on the character of the soil and, to some extent, on that of the crop as well.

## COMMUNITY STUDIES

1. Visit a field that is being plowed. See how the new lands are laid out.

2. Determine the depth of plowing by measuring the land side of the furrow. Also determine the size of the plow by measuring the width of the furrow slice.

3. Estimate the proportion of plowing done in the fall. For what crops is fall plowing most commonly practiced?

4. Examine several plows used in the community. Name the different parts. Determine by the shape of moldboard the type of each plow examined.

5. Ascertain the types of harrows used in the community. Which type do you consider most effective in seed-bed preparation?

6. What type of roller is used most extensively? For what purposes is it used? Is it the best type for the local soil conditions? Why?

7. Visit a corn, cotton, or potato field. Has level or ridged cultivation been practiced? Determine the type of cultivator used. Measure the depth of the cultivated soil. Have the weeds been controlled? Can you find any evidence of root-pruning? Secure information as to the number of cultivations given each of the hoed crops.

## PROBLEM

1. Calculate the acres that would be plowed in a 10-hour day with a two-bottom, 14-inch gang plow, operated at an average speed of 3 miles an hour. (There are 43,560 square feet in an acre.)

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The Cultivation of Corn. Ill. Bul. 259.

# CHAPTER V

## MANURING

Animal manure is the most valuable by-product of the farm. It is in reality a farm-produced fertilizer of tremendous importance. Ordinary farm manure is made up of bedding, dung, and urine. In composition it may be classed as a complete fertilizer since it contains nitrogen, phosphorus, and potassium. However, it is not well balanced, being low in phosphorus. Therefore, its application should be supplemented with a phosphatic material such as superphosphate.[1]

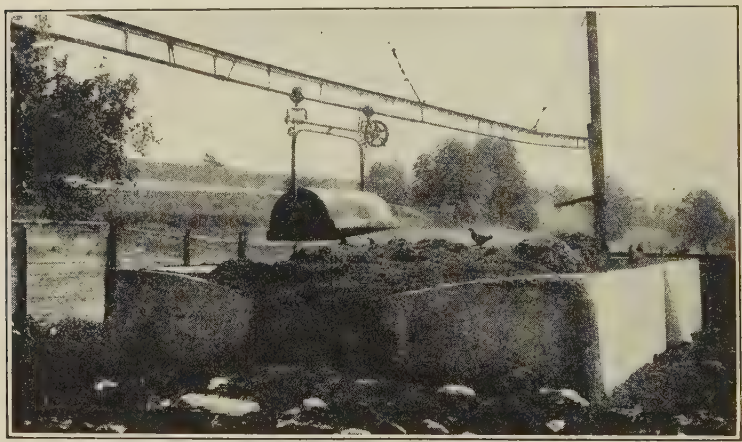

Fig. 109. A Concrete Manure Pit.

**Animal manure is the most valuable by-product of the farm.**

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[1] See General Information at end of chapter for amounts of plant-food regained in farm manure.

More plant-food is supplied to soils by farm manure than by commercial fertilizers. If manure is exposed to the weather in piles, plant-food is leached away at a rapid rate, and owing to decomposition organic matter is destroyed. This loss should be reduced through proper storage or by applying the manure directly to the field.

**Operations:**

1. Applying manure properly.
2. Conserving the manure supply.
3. Manuring different crops.
4. Calculating the amount produced and its value.

### 1. Applying Manure Properly

Some crops are benefited more by manure than others. Light applications are relatively more effective than heavy ones. It is essential that the material be applied evenly, for which purpose a manure spreader is usually required. For the efficient utilization of this most valuable by-product of the farm, use a phosphatic fertilizer material in addition to manure, conserve the plant-food constituents, and apply properly for the right crop.[2]

**Procedure:**

A. Apply with manure spreader.
B. Apply superphosphate or rock phosphate with manure.
C. Utilize manure advantageously.

**A. Apply with manure spreader.** A spreader is essential for the efficient application of manure. With a fork it is almost impossible to apply evenly less than 10 tons to the acre; whereas the manure spreader tears the manure apart and distributes it uniformly at as light a rate as 4 to 6 tons to the acre. By distributing manure with a spreader, greater benefit will be secured. Every farm on which livestock is kept should have a manure spreader.

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[2] See General Information at end of chapter for discussion of benefits of manure.

To get the best returns from farm manure, light uniform applications should be made. Frequent light applications are more effective than heavy ones made at less frequent intervals. The practice, still followed on some farms, of applying 15, 20, and sometimes 30 tons to the acre should be changed.[3] Apply 10, 8, or even as little as 6 tons to the acre at a time, and when possible make the application with a spreader.

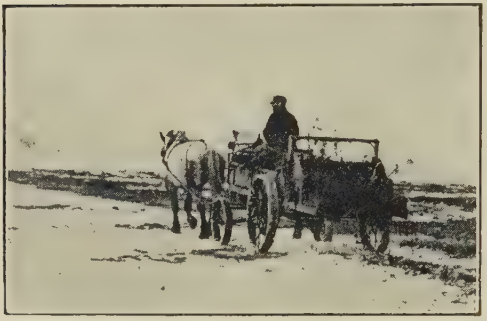

FIG. 110. SPREADING MANURE WITH SPREADER. (Agronomy Dept., N. Y. State Col. of Agr.)

A spreader is essential for the efficient application of manure.

**B. Apply superphosphate or rock phosphate with manure.** The mistake is often made of applying a mixed fertilizer for a grain or hay crop that is being manured. The need of applying a phosphatic fertilizer material,[4] such as superphosphate or rock phosphate, with manure instead of a complete fertilizer is indicated by the difference in the composition of manure and of a complete fertilizer.[5] An average ton of mixed farm manure contains 10 pounds of nitrogen, 5 pounds of phosphoric acid, and 10 pounds of potash. A hundred pounds of a complete fertilizer of the composition frequently applied for the grain crops contains 2 pounds of nitrogen, 12 pounds of phosphoric acid, and 2 pounds of potash. In a 10-ton application of manure there are applied to the acre 100 pounds of nitrogen, 50 pounds of phosphoric acid, and 100 pounds of potash. It would require a 2½-ton application of the complete fertilizer to furnish the nitrogen and potash supplied by 10 tons of manure. A little over 400 pounds of the fertilizer would supply 50 pounds of phosphoric acid, the amount in the 10 tons of the manure. The comparative composition of manure and this complete fertilizer is shown in Fig. 111.

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[3] See General Information at end of chapter for experimental results with different rates of application.

[4] See Chapter VII for explanation of terms *complete fertilizer* and *fertilizer material.*

[5] See General Information at end of chapter for composition of manure from various kinds of animals.

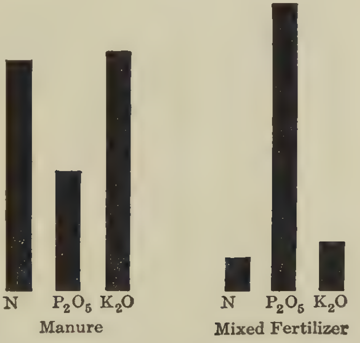

Fig. 111. Composition of Manure and of Mixed Fertilizer.

An average ton of mixed farm manure contains 10 pounds of nitrogen, 5 pounds of phosphoric acid, and 10 pounds of potash. A hundred pounds of a complete fertilizer of the composition frequently used for grain crops contains 2 pounds of nitrogen, 12 pounds of phosphoric acid, and 2 pounds of potash.

The value of superphosphate in addition to manure is clearly shown by the results of an experiment at the Ohio Station. The application of 320 pounds of superphosphate in addition to 8 tons of manure, for corn in a three-year rotation of corn, wheat, and clover, has produced an increase of approximately 10 bushels of corn, 5½ bushels of wheat, and 900 pounds of clover hay each rotation. At 50 cents a bushel for corn, $1 a bushel for wheat, and $10 a ton for clover hay, the crop increase from each 320 pounds of superphosphate would be worth $15. In this case each ton of superphosphate has returned approximately $94 in crop increases. Tabulated results of this experiment are given in Table XVII.

Treat farm manure with either superphosphate or rock phosphate. When treated with superphosphate, it is called *superphosphated manure.* If the manure is applied at the rate of 8 to 10 tons to the acre, use 40 to 50 pounds of the phosphatic material with each ton of manure. Either it can be mixed with the manure in the stall or distributed over the load after it is in the manure spreader. When used in the stable, scatter 20 per cent superphosphate or rock phosphate in the stalls and gutters after they are cleaned, at the rate of 1 to 2 pounds a day for each cow, and cover with bedding. Superphosphate used in this way aids in producing sanitary conditions and acts as a preservative of the nitrogen. It should be used in preference to either lime or gypsum. When distributed over the load of manure, the superphosphate will be sufficiently mixed with manure in spreading. While it is best to apply rock phosphate mixed with manure, superphosphate may be drilled on manured soil at the time the crop is planted. One

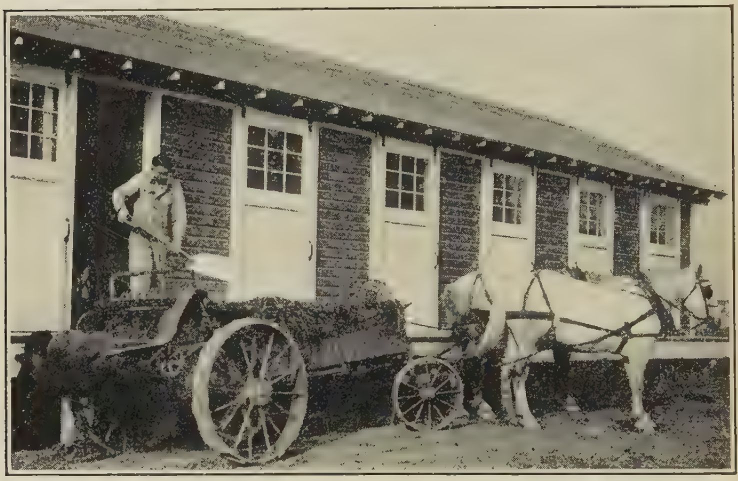

FIG. 112. SPREADING SUPERPHOSPHATE ON A LOAD OF MANURE. (Cooperative Grange League Federation Exchange.)

The superphosphate can be either mixed with the manure in the stall or distributed over the load after it is in the manure spreader.

ton of manure and 40 to 50 pounds of superphosphate will produce nearly the same increase in yield as 2 tons of manure.[6]

In addition to the use of superphosphate, or of superphosphate and manure, it is often desirable, especially with high-value crops, to apply a mixed fertilizer. Even with field corn and the small grain crops, a small amount of a mixed fertilizer applied in the row at time of planting will return a profit, although superphosphated manure has been previously worked into the soil. While the supplementing of superphosphated manure with a mixed fertilizer may often be justified, seldom, if ever, should mixed fertilizer replace superphosphate when manure is used. A good practice is to apply the recommended amount of phosphorus with the manure and to supply besides, as conditions warrant, other fertilization.

**C. Utilize manure advantageously.** For best results apply manure evenly over the field, never in the row. For the cultivated crops, such as corn and cotton, apply before plowing. Where the land is fall-plowed for these crops, and the winter supply of manure used for them, the application must necessarily be made on the plowed land. The practice of piling the manure in the field until after spring plowing in order to apply it to the plowed land cannot be justified. For fall-seeded grain or grass, the manure may be applied advantageously as a top-dressing to the growing crop. If it is applied after the land is plowed there will be more weeds the first year, since the seed carried by the manure will be near the surface ready for germination and growth. There may be a slightly greater loss by leaching if the manure is applied prior to plowing. This loss, consisting largely of nitrogen, is not great, however, if the crop is planted promptly. Where soils are distinctly acid in character, the nitrogen may become available more slowly if the manure is plowed under, as conditions are unfavorable for nitrification.

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[6] See General Information at end of chapter for experimental results from reinforcing manure with superphosphate and with rock phosphate.

Manure is sometimes left in piles to rot in order that the weed seed which it contains may be killed. Such practice is extremely wasteful of both plant-food and organic matter and should not be tolerated on any well-managed farm. To secure the maximum benefit from manure, apply fresh, or store in a properly constructed pit or shed. As a rule, the more promptly it is spread on the land the greater will be the benefit received.[7]

## 2. Conserving the Manure Supply

Three chief causes of the loss of plant-food from manure are: (1) the direct loss of the liquid manure, (2) decomposition, and (3) leaching. To secure the full fertilizing value of manure, these three sources of loss must be controlled.

**Procedure:**

A. Save the liquid manure.
B. Do not expose the manure in piles.
C. Store properly.
D. Use a preservative.
E. Haul directly to the field and spread.
F. Utilize poultry manure.

**A. Save the liquid manure.** Nearly half the plant-food of animal excrement is found in the liquid manure, which is particularly rich in both nitrogen and potash. The plant-food that it contains is in a readily available form and can be used almost immediately by the growing crops. The conservation of liquid manure is the first essential in the economic utilization of the farm supply of manure.[8]

The first requirement for the successful conservation of the liquid manure is a water-tight floor. Concrete is best, though a well-constructed board floor is satisfactory. Earth or clay floors have been shown to be inadequate for the conservation of the liquid manure.

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[7] See General Information at end of Chapter VIII for directions for making artificial manure.

[8] See General Information at end of chapter for composition of liquid manure.

A concrete cistern or pit may be used as storage for this liquid. However, liquid-manure cisterns have not been found practical on many farms. Instead, use an adequate amount of bedding to absorb the liquid. The efficiency with which the manure is saved will depend on the tightness of the floor and on the quality and amount of bedding used. Straw is one of the best materials for bedding livestock. It is a good absorbent and is considered a crop residue or a by-product on most farms. Other refuse material, such as cornstalks, buckwheat hulls, and poor-quality hay, may be used as bedding. Cornstalks shredded so that the pith is exposed make an excellent absorbent. The resulting manure can readily be distributed with either a spreader or a fork.[9]

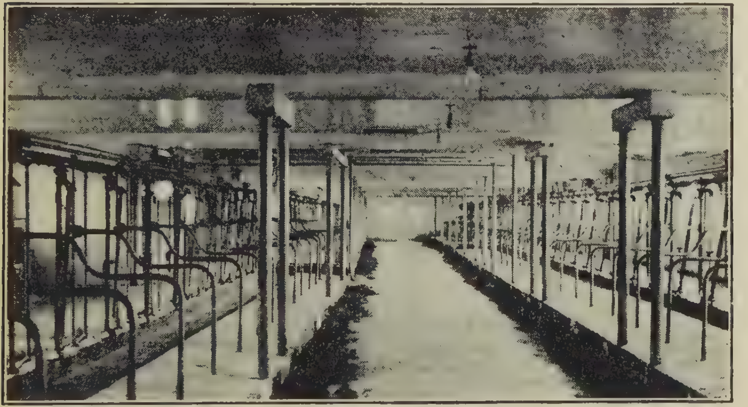

FIG. 113. A WELL-BEDDED DAIRY BARN.

The first requirement for the successful conservation of the liquid manure is a water-tight floor. The efficiency with which the manure is saved will depend on the tightness of the floor and on the quality and amount of bedding used.

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[9] See General Information at end of chapter for composition of different bedding materials.

The practice of using the dung from horses as an absorbent in the cow barn is often followed. It may be objectionable from the standpoint of sanitation, but if proper precaution is taken it need not be unsanitary. Place the horse manure in the gutters back of the cows after cleaning the stable, and cover promptly with straw or other clean bedding material. If a small amount of superphosphate is distributed on the horse dung after it has been placed in the gutter, odors will be controlled and the fertilizing value of the resulting manure greatly improved.

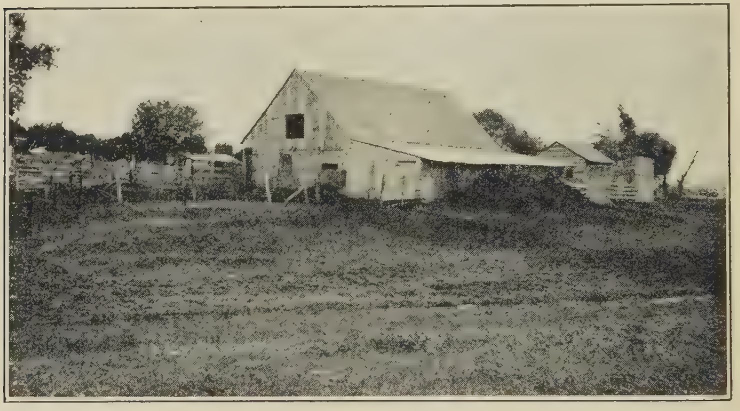

Fig. 114. Manure Exposed in the Barnlot.

If manure is exposed in piles, particularly under the eaves of the barn, there is a rapid loss not only of plant-food but also of the organic matter.

When there is an insufficient supply of by-product bedding material, supplement it with shavings, sawdust or peanut hulls. These materials have satisfactory absorptive qualities; and, contrary to common belief, the manure containing sawdust or shavings is generally of approximately equal value to that in which straw or some other crop residue has been used as bedding. Although the composition of the bedding has its ultimate influence on the productivity of the soil, the effect on the value of each ton of manure depends more on its absorptive quality than on its composition. Therefore arrange to use a liberal amount of some bedding material having high absorptive qualities. The choice between materials will depend on conditions, but cost, absorptive qualities, and composition should be taken into consideration.

**B. Do not expose the manure in piles.** If manure is exposed in piles, particularly under the eaves of the barn, there is a rapid loss not only of plant-food but also of the organic matter. The loss is due to the combined effect of decomposition and leaching.[10]

Bacteria cause the decomposition of manure. In the process, organic matter is destroyed, and nitrogen is liberated and may be lost by volatilization in the form of ammonia gas, or by leaching in the form of soluble nitrogenous salts.[11] The mineral plant-food content of the organic matter also becomes soluble as the manure decomposes, and it may be lost by leaching. The action of the beneficial bacteria of nitrification is necessary for the liberation of the plant-food content of the manure, but the action should take place after the manure is spread on the land, or when it is in proper storage, rather than when it is piled in the barnlot or in the field.

The higher the temperature and the heavier the rainfall, the more rapid will be the loss from manure in an exposed pile. Consequently, it is less objectionable to expose manure in winter than in summer. Unfortunately, manure exposed during the winter cannot ordinarily be distributed until such a late date that it is subjected to severe leaching by spring rains. The loss is relatively less when the pile is properly shaped and well firmed, but is sufficiently rapid to constitute a tremendous loss of plant-food.

If manure is thrown into the barnlot or otherwise exposed to the weather, the first big loss is due to the leaching out of the liquid manure and its replacement with rain water. Fresh manure from horses and cows contains 70 and 80 per cent, respectively, of moisture. This moisture has come largely from the animal, and is rich in nitrogen and potash. Better conservation of manure would result if farmers appreciated the fertilizing value of the liquid portion.

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[10] See General Information at end of chapter for amounts of plant-food lost from exposed manure.

[11] See Chapter I for explanation of essentials of agricultural chemistry.

As decomposition progresses in exposed piles of manure, phosphorus and potassium, as well as nitrogen, change to a soluble form and are subject to loss by leaching. It is this combined action of decomposition and leaching that progresses undisturbed for months when manure is placed in exposed piles. Up to 50 per cent or more of the plant-food content of manure may be lost during five or six months of summer exposure.

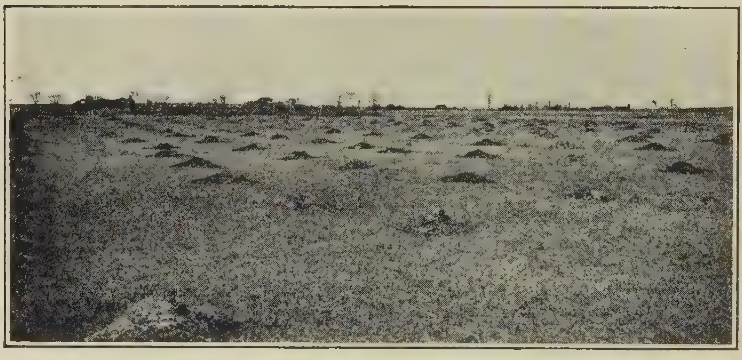

FIG. 115. MANURE DISTRIBUTED IN PILES.

The practice of distributing manure over the field in small piles, to be left for several months before spreading, is very wasteful.

The practice of distributing manure over the field in small piles, to be left for several months before spreading, is equally wasteful. Both decomposition and leaching progress at a rapid rate. As a result there is an excessive accumulation of plant-food in the soil under the piles. Although the leaching may be more rapid when the manure is spread on the field, the plant-food leaches into the surface soil of the whole field rather than in the restricted areas occupied by the piles. The plant-food which passes into the soil is largely fixed and held in the surface. The nitrogen will be carried down and out of the soil when the temperature is adequate for nitrification to take place. Where this happens, crops are generally planted and utilize this available nitrogen before any great amount leaches away. However, they are not able to make good use of the large accumulations in the areas where the manure has been applied in small piles. A large pile on the field or even in the barnlot is less wasteful than many small piles over the field.

Considerable loss may result where manure is distributed over a field and left exposed to air and sunshine in warm, dry weather. Therefore, when practical, incorporate it with the soil by plowing or disking. Obviously, this cannot be done if a crop occupies the land, but experience shows that the top-dressing of grass land and of winter grain is a practical and efficient use of manure. Since most manure is applied during winter and spring months when the soil normally does not dry out, the manure remains moistened. However, in the North, the manure freezes, and as a result considerable loss of nitrogen takes place. To prevent excessive loss from manure, either provide proper storage or haul it to the field daily and spread, and when practical incorporate it with the soil without undue exposure.

**C. Store properly.** Manure stored in a water-tight pit or in a covered shed is preserved with little loss. A covered shed with concrete floor and sides is best. It should be located so that the manure can be transported to it from the stable by means of a manure carrier, thus eliminating additional handling. Keep the manure compacted or thoroughly moistened when in storage. A good arrangement is to have the shed accessible to farm animals so that they will keep the manure tramped.

**D. Use a preservative.** If manure is stored, use a preservative with it. Superphosphate is the best material for this purpose. It has been found very effective in conserving nitrogen that might otherwise be lost as the result of volatilization as ammonia. At the same time it adds phosphorus, which is the deficient plant-food element in manure. Gypsum, like superphosphate, will conserve ammonia, but is inferior to it in that it adds no phosphorus. Rock phosphate supplies phosphorus and has a slight preservative effect when mixed with manure, but it is not so efficient a preservative as superphosphate.[12]

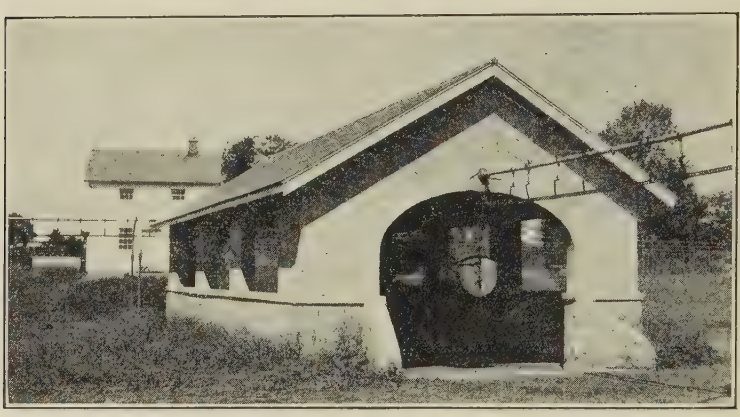

FIG. 116. A WELL-CONSTRUCTED MANURE SHED.

Manure stored in a water-tight pit or in a covered shed is preserved with little loss.

Another satisfactory way of using superphosphate as a preservative is to scatter it over the manure every few days as a new layer accumulates in the manure shed. Apply at the rate of 40 to 60 pounds of the 20 per cent grade to the ton of manure. If the manure is treated in this way, additional superphosphate need not be added to the crop manured. In fact, an 8- to 10-ton application of reinforced manure can be counted on to produce good yields of grain and hay for a period of several years. Unless superphosphate or rock phosphate is applied with the manure, it will be necessary, for the best results, to make a separate application of some phosphatic fertilizer material, preferably superphosphate.

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[12] See Table XVII in General Information at end of chapter for Ohio results with treated manure.

**E. Haul directly to the field and spread.** Throughout much of the year it is practicable to haul manure to the field from day to day as it is produced. Where this is done and the manure spread immediately, there is little loss of plant-food, except when it dries before being leached by rain. Even though the fields are covered with snow, the manure may still be applied unless the snow becomes too deep to permit the use of the spreader. It should then be hauled to the field in a sled and spread with a fork. When applying with a fork there is a tendency to make too heavy an application. It is also difficult to distribute the manure uniformly with a fork. So long as the application is made to relatively level fields, the

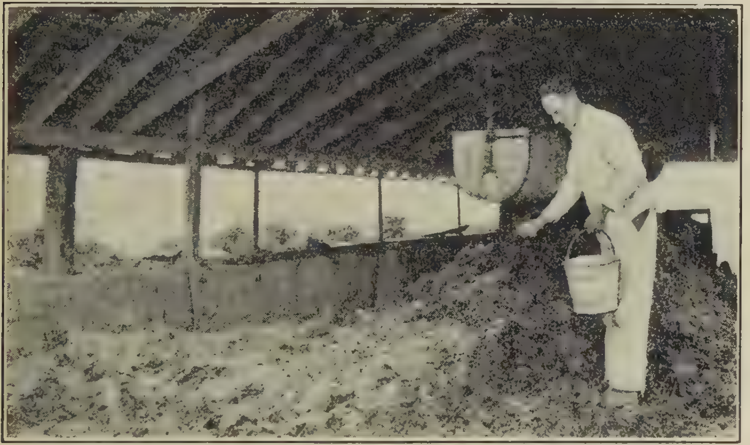

Fig. 117. Use Superphosphate as a Preservative.

Another satisfactory way of using superphosphate as a preservative is to scatter it over the manure every few days as a new layer accumulates in the manure shed.

loss will not be great even though applied to snow-covered, frozen ground. During the summer season there are periods when, because crops are growing on all the fields, there is no available place to apply the manure. It must either be put on pasture land or be held for a short period until a crop is harvested. However, this does not become a serious problem since animals are generally on pasture at this season, and there is not much manure produced in the barn. A manure storage shed or pit of moderate size can be utilized to advantage on most livestock farms even though the general practice is to haul the manure directly to the field. As far as possible, plan to spread the manure regularly as it is produced, thereby avoiding the necessity of storing over long periods.

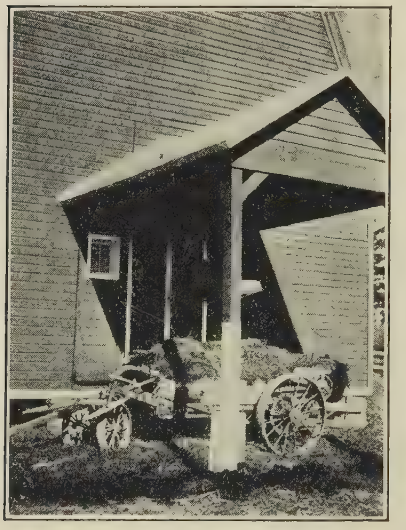

FIG. 118. LOAD THE SPREADER AS MANURE IS REMOVED FROM THE STALLS.

Throughout much of the year it is practicable to haul manure to the field from day to day as it is produced. Where this is done and the manure spread immediately, there is little loss of plant-food.

**F. Utilize poultry manure.** Poultry manure is richer in plant-food than that from the larger animals.[13] This is due partly to the greater concentration of poultry rations, but largely to the lower water content of the manure. The supply should be carefully preserved and properly applied.

Scatter sawdust or some other fine-textured bedding material on the dropping boards of the poultry house at the rate of approximately 4 pounds to each 10 pounds of manure. The sawdust absorbs the moisture and improves the mechanical condition of the manure. In this way lumping is prevented and greater ease of application is insured.

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[13] See Table VIII in General Information at end of chapter for composition of poultry manure.

When the manure is removed, which should be done frequently, mix about one pound of superphosphate with each 10 pounds of manure or 14 pounds of manure and sawdust. Another good method is to scatter the superphosphate on the dropping boards just prior to distributing the sawdust. Use at the rate of 2 to 3 pounds daily to 100 hens. The superphosphate applied in this way has a double purpose: it prevents the loss of ammonia, and it furnishes phosphoric acid which is the deficient plant-food in the manure. Where the manure is to be applied for vegetables, or for ordinary field crops on soils low in potash, add, in addition to the superphosphate, ¼ to ½ pound of muriate of potash to each 10 pounds of excrement.

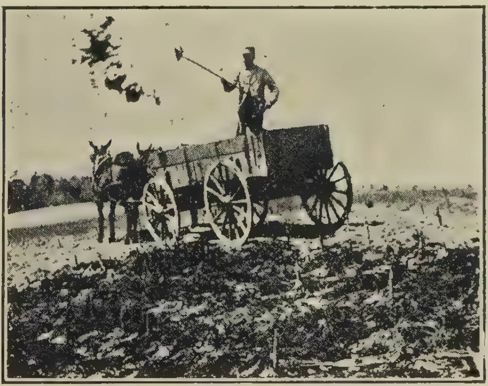

FIG. 119. APPLYING MANURE WITH A FORK. (Agronomy Dept., N. Y. State Col. of Agr.)

When applying with a fork there is a tendency to make too heavy an application. It is also difficult to distribute the manure uniformly.

The practice, sometimes followed, of drying and pulverizing poultry manure cannot be justified. The work is disagreeable and adds little to the fertilizing value of the product. The commercial dried and pulverized manures are entirely too expensive to use in field-crop production. For the treatment of lawns, small city gardens, and greenhouse soils, commercial manures can be used to advantage. Poultry manure if thoroughly dried will produce fully as good results as commercial manures when applied at an equivalent rate. When a very light application is to be made for vegetables, apply in the row, but mix with the soil previous to the planting of the seed. Applications of 5 tons or more to the acre should be applied broadcast.

## 3. Manuring Different Crops

There is no one best crop for which to use manure. In practice, manure will be applied for several different crops on most farms. The conditions under which the various crops should be manured must be understood.[14]

**Procedure:**

A. Manure corn, cotton, and tobacco.
B. Determine whether or not to manure small grains.
C. Top-dress meadows and pastures with manure.
D. Determine whether alfalfa and clover need manure.
E. Manure vegetable crops.
F. Apply manure for fruit.

**A. Manure corn, cotton, and tobacco.** Corn needs a large amount of nitrogen. Its profitable production requires one of three conditions: (1) a soil well supplied with nitrogen, (2) a good sod plowed under, or (3) an application of farm manure. In fact, unless a heavy sod is being plowed under, an application of manure is essential for a profitable corn crop on any but the richer prairie soils. Even on these soils provision must be made for the return of farm-produced organic matter and nitrogen, or yields will ultimately become unprofitable. Fertilizer nitrogen is too costly to be used in large amounts for field corn.

Of the grain crops, corn responds best to farm manure.

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[14] See General Information at end of chapter for residual effect of manure.

Apply 6 to 10 tons of manure to the acre for field corn except when grown on soil well supplied with organic matter or where a clover or alfalfa sod is plowed down. Even under these conditions corn will respond to manure, and there is little danger of supplying an excess of nitrogen for this crop.

Cotton, like corn, has a high-nitrogen requirement. Because little livestock is kept in the Cotton Belt and the animals are on pasture a large part of the year, the supply of manure is limited, and seldom is any available for cotton land. Consequently it is largely replaced by green-manure crops and commercial fertilizers high in nitrogen. Ordinarily cotton sells at a price that will return a profit from fertilizer nitrogen, differing in this respect from field corn. Where manure is available, apply at the rate of 10 tons to the acre for cotton.

FIG. 120. CORN ON MANURED LAND.

Unless a heavy sod is being plowed under, an application of manure is essential for a profitable corn crop on any but the richer prairie soils.

The cigar tobacco grown in the northern states responds to manure, but the cigarette and pipe tobacco produced in the South is injured in quality by manure unless the rate of application is very light. Apply manure at the rate of 10 to 15 tons to the acre for the dark-colored cigar tobacco, but do not manure land that is to be used for bright tobacco. Avoid applying excessive amounts for the light-colored grades of tobacco used for cigar wrappers.

**B. Determine whether or not to manure small grains.** Of the small grains, wheat and barley respond best to manure. Their need for manure can be determined by the growth of straw, for if a sufficient growth of straw is obtained for a maximum yield without manure, its use would tend to cause lodging. Under such conditions apply it for some other crop in the rotation. However, except on very rich soils, manure may be used for both wheat and barley. Of the two, wheat, because of the less favorable place it commonly occupies in the rotation, is more in need of manure. When barley follows manured corn, do not apply additional manure for the barley.

Fig. 121. Applying Manure to a Timothy Meadow.

When timothy or other grass hay is left on the land for two years, it furnishes an excellent place for manure.

Winter wheat and barley, and in the South fall-seeded oats, can often be top-dressed to advantage with manure during the winter. This method of application will conserve the maximum amount of plant-food; it may to a certain extent reduce winter injury; and it will produce very favorable conditions for clover and timothy. If a supply of manure is available in the late summer, and time permits, it may be plowed under for wheat, or applied after plowing and disked into the topsoil.

Oats and rye are less in need of manure than corn and wheat. When following manured corn, the oat crop will be furnished sufficient nitrogen by the residual effect from the manure applied for the corn, and additional manure would be liable to cause serious lodging. Rye is capable of utilizing soil nitrogen most efficiently, as is also buckwheat. These crops are seldom manured. In the common four-year rotation of corn, oats, wheat, and hay, two light applications of manure could be made to advantage, one for corn and one for wheat.[15]

**C. Top-dress meadows and pastures with manure.** When timothy or other grass hay is left on the land for two years, it furnishes an excellent place for manure. Top-dress the second-year timothy with manure in preference to manuring the corn. The practice of leaving the land in grass hay for several years should be discouraged from the standpoint of soil improvement, for the soil becomes depleted unless the meadow is top-dressed with manure or with a commercial fertilizer high in nitrogen. However, if grass hay is left down for more than two years, it is essential that it be supplied with nitrogen from either manure or fertilizer. Manure may be applied to meadows any time during the winter or early spring. Distribute it at a light rate with a spreader. Coarse manure is objectionable for top-dressing meadows because of the trash which is raked up with the hay.

Permanent pastures may often be top-dressed advantageously with superphosphated manure. They offer an opportunity for the use of the summer-produced manure which cannot be applied to the cropped land at this season. As a rule, pastures should not be manured so long as the manure supply can be used advantageously for grain and hay or when the pasture soil has a high-fertility level.[16]

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[15] See Chapter IX for treatment of field-crop rotations.

**D. Determine whether alfalfa and clover need manure.** As a rule it is not a good practice to apply manure directly for clover or alfalfa. If inoculated, these legumes have the power of securing an adequate amount of nitrogen from the atmosphere. When supplied with available nitrogen, through an application of either fertilizer or manure, they may use less atmospheric nitrogen. For alfalfa, manure is particularly objectionable because it encourages the growth of weeds and grass, which often crowd out the alfalfa. Do not apply manure for alfalfa or clover when soil conditions are favorable for these legumes.

The practice of top-dressing the new seeding of clover can be justified only where soils are so poor that the clover will fail unless manured. Lime and superphosphate in addition to manure, for a grain crop in the rotation, will produce favorable conditions for clover and obviate the necessity of manuring the new seeding. Unless the soil conditions are favorable for clover, the new seeding should be manured, preferably with superphosphated manure. When fall-seeded wheat is used as a nurse crop for clover, apply the manure as a winter top-dressing except where the practice will result in lodging. The wheat will utilize the readily available nitrogen from the manure so that the effectiveness of the clover in utilizing atmospheric nitrogen should not be greatly lessened.

Manure has been found to be beneficial in securing a catch of alfalfa. Applied the year the alfalfa is planted, it favors the development of weeds and grass. Apply the manure for the crop preceding alfalfa so that the weed seed may germinate before the alfalfa is seeded. By applying the manure to the preceding crop, the available nitrogen of the manure will be largely utilized before the alfalfa is planted and will not stimulate the growth of grass and weeds in the newly seeded alfalfa. Even though the practice of top-dressing established alfalfa fields with manure is widely advocated, it is seldom the best use of manure. Weeds and grass are benefited more than the alfalfa; and, even though the hay crop may be increased, it is seldom that greater returns would not have been secured from manure if applied for some other crop. In general use superphosphate, superphosphate and potash, or a 0-20-10 fertilizer instead of manure for the top-dressing of alfalfa.

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[16] See Chapter X for treatment of pastures.

**E. Manure vegetable crops.** Practically all vegetable crops are greatly benefited by farm manure. Excessive applications may produce too great top growth of root and tuber crops. However, both Irish and sweet potatoes respond well to farm manure. Do not apply manure directly for Irish potatoes where it is difficult to produce clean tubers, as manure favors the development of scab. In general, it is best to apply the manure for the preceding crop. The potato crop will get the residual effect of the plant-food, and at the same time the manure will have largely decomposed and become thoroughly incorporated with the soil. It will thus have its maximum effect in producing a loose, friable condition of the surface soil which is so essential for potatoes. If applied directly for the potato crop, make the application in the fall and plow under.

The vegetable garden should receive an application of 12 to 20 tons of manure to the acre annually, as a source not only of plant-food but also of organic matter. Apply the manure uniformly over the surface and plow it into the soil. When garden soils are thus manured, their physical condition is favorable for maximum production. Apply superphosphate or a mixed fertilizer high in phosphoric acid, in addition to the manure, at the same time as or just previous to planting.

Such field-produced vegetables as cabbage, tomatoes, and sweet corn should receive, where available, an application of 10 to 15 tons of manure to the acre. Do not manure the vegetable legumes, such as peas and beans, except on very poor soil. Apply mineral fertilizer, particularly superphosphate, in addition to manure for all vegetables. A potash fertilizer material, and with some vegetables a little nitrate of soda or sulfate of ammonia, will give additional benefit.[17]

**F. Apply manure for fruit.** Manure may be used to advantage in fertilizing fruit. Nitrogen is the plant-food most often needed as a fertilizer by the fruit crop. Manure supplies this nutrient in large amounts. It has been found beneficial not only in increasing the yield but likewise in producing healthy foliage, stimulating wood and spur growth, and increasing the set of fruit. In applying manure to orchards, scatter uniformly around the trees extending from within a foot or two of the trunk well beyond the extent of limb growth. With a young orchard the manure should extend a distance of 8 or 10 feet from the tree irrespective of limb growth and may, in fact, be broadcast uniformly over the whole surface. The amount to apply to mature trees will vary with the size as well as with the kind of fruit. Apply 200 to 300 pounds to the tree in mature apple orchards. Make the application in the winter or early spring. If applied during the summer months, manure will retard the maturing of the fruit. The manuring of late varieties of peaches and grapes may prevent their ripening in sections having a short growing season.[18]

## 4. CALCULATING THE AMOUNT PRODUCED AND ITS VALUE

The approximate amount of manure that will be produced on a given farm may be readily calculated with fair accuracy. This calculation may be made either on the basis of the kind and number of livestock kept or on the amount of feed and bedding used.

**Procedure:**

A. Calculate the amount of manure produced.
B. Calculate the value of the manure.

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[17] See Chapter XI for treatment of garden soils.

[18] See Chapter XII for treatment of orchard soils.

**A. Calculate the amount of manure produced.** The amount of excrement produced by 1000 pounds live weight of the various kinds of farm animals is given in Table XV. From this information can be figured the annual production of manure by an animal of a known weight, and, in fact, the total production of manure by all animals on a given farm. Add to the weight of the solid and liquid excrements the weight of bedding. As an average of all classes of animals, figure bedding as constituting one-eighth the weight of the manure, that is, add 1 pound of bedding for each 7 pounds of excrement. A ton of manure would then be made up of 1750 pounds of excrement and 250 pounds of bedding.

The manure produced by farm animals is never all available for application to the soil. It has been estimated that, on the average, one-third of the manure is lost. Consequently, in calculating the amount of manure that would be produced in the barn and available for application to the land, use two-thirds the amount of excrement given in Table XV. Farmers often figure roughly that a cow or horse will produce a ton of manure a month, or 12 tons yearly. Assuming that two-thirds is produced in the stable, there would be available yearly 8 tons of manure per animal for direct application to the land. Obviously, in sections where the climate is mild, animals will be in the stable for a shorter period during the year, resulting in a reduced annual production of manure for application to cropped land.

Another method of determining the amount of manure produced is to base the calculation on the feed consumed and the bedding used. Owing to the destruction of organic matter by digestion, the dry matter of the feed is never entirely recovered in the manure. Grains and concentrated mill feeds are very digestible, whereas roughage, such as hay and straw, has a low digestibility. Of the average mixed ration, about two-thirds of the organic matter is destroyed by digestion. This means that only one-third is regained in the manure. Therefore, divide the weight of the dry matter in the feed by

3 to get the weight of dry matter in the excrement. Add to this figure the dry matter in the bedding, to determine the total dry matter in the manure. To calculate the amount of manure produced, multiply the weight of total dry matter by 4, since farm manure contains approximately 25 per cent, or one-fourth, dry matter, and 75 per cent, or three-fourths, water. The mathematical procedure for this method of calculating the total amount of manure produced may be represented by the following formula:

$$\left(\frac{\text{dry matter in feed}}{3} + \text{dry matter in bedding}\right) \times 4 = \text{total amount of manure.}$$

On the average in the northern states, about two-thirds of this amount should be available for application to the soil.

**B. Calculate the value of the manure.** The value of manure depends largely on its plant-food content. One method of calculating its value is to evaluate the nitrogen, phosphoric acid, and potash on the basis of their cost in standard fertilizer materials. When nitrogen, phosphoric acid, and potash are valued at 15, 6, and 5 cents a pound respectively, a ton of average farm manure, containing 10 pounds of nitrogen, 5 pounds of phosphoric acid, and 10 pounds of potash, contains $2.30 worth of plant-food. The nitrogen constitutes nearly two-thirds, and the phosphoric acid and potash combined only one-third of this amount. If the plant-food is evaluated on the basis of its average cost in a factory-mixed fertilizer, the value of a ton of manure is about $3. The plant-food supplied in a 10-ton application of manure would cost approximately $30, if purchased as a factory-mixed fertilizer.

The real value of manure to the farmer can best be ascertained from the results of carefully conducted field experiments in which manure has been applied in regular amounts over a period of several years. The valuation of a ton of manure may be determined very definitely by comparing the value of the crops secured from manured and from unmanured land. By this means it has been found that a ton of manure is worth $1 to $2 when used for grain and hay crops. It is worth considerably more when used on vegetable crops grown intensively. When properly treated with superphosphate, its value as measured by crop increases is nearly doubled.

## GENERAL INFORMATION

### 1. Composition of Farm Manure

The term *farm manure* is commonly restricted to the excreta of farm animals. In addition to the solid and liquid excrement, it contains varying amounts of litter or bedding. The term *stall manure* refers to fresh, unexposed material; by *yard manure* is meant that which is more or less decomposed and leached, owing to exposure to the weather. The terms *fresh* and *rotted* are also used to designate these two forms of manure. The expression *manuring the land* should be restricted to the direct application of the excreta of farm animals, so that this procedure can be distinguished from that of *fertilizing the land* which properly refers to the application of commercial fertilizers. Certain crops are referred to as *green manures,* and the process of returning them to the soil, as *green manuring.* These terms can readily be distinguished from those applied to the excreta of farm animals.

Unexposed farm manure has an average composition of 10 pounds of nitrogen, 5 pounds of phosphoric acid, and 10 pounds of potash to the ton. Nevertheless, it varies in composition. It is of interest to understand the factors which influence the plant-food content of manure and to learn more about the composition of the different kinds.

Mixed manure when fresh contains about 75 per cent of water. The water and consequently the dry-matter content will vary under certain conditions. If the moisture content should increase from 75 to 80 per cent, the dry matter would be reduced by one-fifth, from 25 to 20 per cent. A relatively small increase or decrease in the water content will change materially the plant-food content. In exposed manure particularly, the moisture content may be increased to such an extent as greatly to lessen the percentage of plant-food. The relative amounts of dung, urine, and bedding likewise influence composition, as does also the quality of the bedding. From the practical standpoint these factors should not be overlooked as they influence materially the composition of manure as found on the farm.

TABLE VIII

Percentage of Plate-Food Constituents in Fresh Animal Excrements *

| Kind of Animal | Excrement | | Water | Nitrogen | Phosphoric Acid | Potash |
|---|---|---|---|---|---|---|
| | Portion | Per Cent of Total | Per Cent | Per Cent | Per Cent | Per Cent |
| Cow | Solid | 70 | 85 | 0.40 | 0.20 | 0.10 |
| | Liquid | 30 | 92 | 1.00 | Trace | 1.35 |
| | Mixed | .. | 86 | 0.60 | 0.15 | 0.45 |
| Horse | Solid | 80 | 75 | 0.55 | 0.30 | 0.40 |
| | Liquid | 20 | 90 | 1.35 | Trace | 1.25 |
| | Mixed | .. | 78 | 0.70 | 0.25 | 0.55 |
| Pig | Solid | 60 | 80 | 0.55 | 0.50 | 0.40 |
| | Liquid | 40 | 97 | 0.40 | 0.10 | 0.45 |
| | Mixed | .. | 87 | 0.50 | 0.35 | 0.40 |
| Sheep | Solid | 67 | 60 | 0.75 | 0.50 | 0.45 |
| | Liquid | 33 | 85 | 1.35 | 0.05 | 2.10 |
| | Mixed | .. | 68 | 0.95 | 0.35 | 1.00 |
| Chicken | Mixed | .. | 55 | 1.00 | 0.80 | 0.40 |

* Van Slyke, "Fertilizers and Crop Production," p. 218, Orange Judd Co, New York.

Even though there is rapid loss of plant-food from manure during exposure, the composition of fresh and rotted manure is not dissimilar. This is because the loss in weight resulting from the decomposition of organic matter occurs at about the same rate as the loss of plant-food. Rotted manure contains on the average 10 pounds of nitrogen, 8 pounds of phosphoric acid, and 10 pounds of potash to the ton. When decomposed in storage, the plant-food content would not only be greater, but it would likewise be more available.

**A. Solid and liquid excrement.** The solid excrement, or dung, consists largely of the undigested portion of the food consumed. The material has been made fine by mastication and softened by the admixture of the various digestive fluids, but in composition it is not unlike the coarser portion of the ration from which it has been largely derived. As an average, it contains one-half of the nitrogen, one-third of the potash, and practically all the phosphoric acid. There must be further decomposition of this material before the plant-food in it becomes available for plant growth.

TABLE IX

RELATIVE AMOUNTS OF NITROGEN, PHOSPHORIC ACID, AND POTASH IN SOLID AND LIQUID EXCREMENTS *

| Kind of Animal | Percentage of Total Nitrogen in | | Percentage of Total Phosphoric Acid in | | Percentage of Total Potash in | |
|---|---|---|---|---|---|---|
| | Solid | Liquid | Solid | Liquid | Solid | Liquid |
| Horse......... | 62 | 38 | 100 | 0 | 56 | 44 |
| Cow.......... | 49 | 51 | 100 | 0 | 15 | 85 |
| Pig........... | 67 | 33 | 88 | 12 | 57 | 43 |
| Sheep......... | 52 | 48 | 95 | 5 | 30 | 70 |
| Average....... | 57 | 43 | 95 | 5 | 40 | 60 |

* Van Slyke, "Fertilizers and Crop Production," p. 221, Orange Judd Co., New York.

The liquid manure is composed of the material in the digested portion of the food that is rejected by the animal body. It contains about one-half of the nitrogen, two-thirds of the potash, but practically none of the phosphoric acid of the original plant-food material. The plant-food is in a readily available form and is subject to serious leaching unless the manure is properly cared for.

Definite information as to the relative weight and composition of solid and liquid excrements of farm animals is given in Table VIII. Information as to the relative amounts of nitrogen, phosphoric acid and potash in solid and liquid excrements is given in Table IX.

**B. Composition of bedding.** The bedding influences the composition of the manure slightly, depending on its own composition as compared with that of the solid and liquid excrements; and, more definitely, depending on its efficiency in absorbing and conserving the liquid manure. Plenty of high-grade bedding should be used on the ordinary farm as a means of absorbing the liquid manure.

TABLE X

POUNDS OF PLANT-FOOD PER TON OF BEDDING MATERIALS

| Kind of Material | Nitrogen | Phosphoric Acid | Potash |
|---|---|---|---|
| Wheat straw | 11.5 | 4.4 | 12.6 |
| Oat straw | 11.0 | 5.6 | 35.4 |
| Peat | 40.0 | 4.0 | 2.0 |
| Sawdust | 5.0 | 6.0 | 14.0 |
| Shredded cornstalks | 14.8 | 8.0 | 18.0 |

The average composition of the more common bedding materials is given in Table X.

The nitrogen of peat will not become available rapidly, and little if any of the plant-food in sawdust is of practical value in crop production.

**C. Kind of animal.** There is a great variation in the composition of manure from different animals. The variation is due largely to the difference in moisture content. Horse and sheep manures are low in water and are known as *hot manures.* They decompose easily and during the process give off a great deal of heat. Hog and cow manures, on the other hand, are high in water and are called *cold manures.* The dry manures are more concentrated in plant-food since they contain more dry matter. Precaution should be taken to prevent the hot manures from heating when they are placed in storage, at which time, unless mixed with cold manures, it is essential that they be well tramped. Water can often be added to advantage when the manure is stored in a water-tight pit. Table XI gives the average composition of manure from the common farm animals.

TABLE XI

COMPOSITION OF EXCREMENT FROM DIFFERENT ANIMALS—POUNDS OF CONSTITUENTS PER TON

| Kind of Animal | Pounds of Nitrogen | Pounds of Phosphoric Acid | Pounds of Potash |
|---|---|---|---|
| Cow | 12 | 3 | 9 |
| Horse | 14 | 5 | 11 |
| Pig | 10 | 7 | 8 |
| Sheep | 19 | 7 | 20 |
| Hen | 20 | 16 | 8 |

**D. Nature of feed.** The kind of feed is perhaps the factor which has the most influence on the composition of manure. The concentrates—mill feeds and grains—have a high content of digestible nutrients. The roughages—hay, straw, and silage—usually contain a low per cent of nutrients, and are always low in digestibility. If animals are fed a large proportion of concentrates, the resulting manure is rich in plant-food; whereas, if they are maintained largely on roughage, the manure is correspondingly low in plant-food. The potash content is an exception, as the roughages run higher in this element than do many of the concentrates. Because of this, manure from animals fed largely on concentrates is somewhat lower in potash than if considerable roughage is fed.

**E. Type of work and age of animal.** Both the type of work an animal is doing and its age influence the composition of the manure. When a mature animal is being fattened, practically all the plant-food is given off in the manure. Even when at work, other than that of milk production, a mature animal appropriates little of the plant-food for body use. A dairy cow, when producing a heavy flow of milk, will utilize a considerable amount of plant-food, lessening that in the manure. Too, a young, growing animal requires both phosphorus and nitrogen for the building of bone and flesh. A growing calf or colt will utilize in body building 3 to 4 pounds of phosphorus annually; a cow requires nearly 6 pounds of nitrogen, 1 of phosphorus, and 1¼ of potassium, for each thousand pounds of milk produced.

TABLE XII

ELEMENTS GIVEN IN FEED AND RECOVERED IN MANURE ON CEMENT AND EARTH FLOORS

| | On Cement Floor | On Earth Floor |
|---|---|---|
| Nitrogen in feed, etc., pounds | 2685 | 2756 |
| Nitrogen in manure, pounds | 2006 | 1719 |
| Nitrogen, per cent recovered | 74.7 | 62.4 |
| Phosphorus in feed, etc., pounds | 1033 | 977 |
| Phosphorus in manure, pounds | 799 | 771 |
| Phosphorus, per cent recovered | 77.5 | 78.9 |
| Potassium in feed, etc., pounds | 1212 | 1176 |
| Potassium in manure, pounds | 1064 | 922 |
| Potassium, per cent recovered | 87.8 | 78.4 |

## 2. PLANT-FOOD REGAINED IN MANURE

At best, only part of the fertilizing value of the feed is regained in the manure. Not only is organic matter destroyed by digestion, but also the animal utilizes part of the plant-food which becomes available. As explained, the proportion utilized by the animal varies, but it has been estimated that on the average it amounts to one-fourth the nitrogen, one-fifth the phosphorus, and one-tenth the potassium contained in the feed. In practice, an additional loss, generally in excess of that

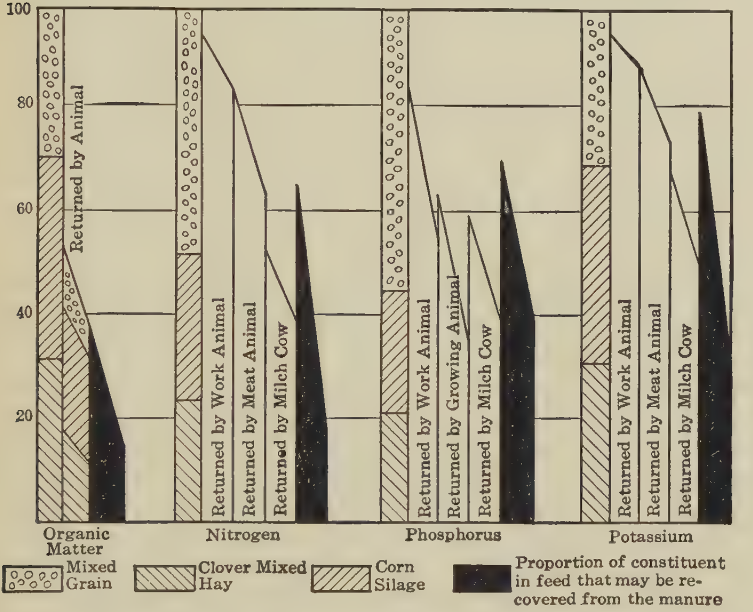

FIG. 122. PROPORTION OF CONSTITUENTS IN ANIMAL FOODS REGAINED IN THE MANURE.

The blocks at the left of each group represent the distribution of 100 pounds of the constituent among the several foods consumed. The middle blocks show the proportion of the constituent returned by the animal in the manure. The right-hand blocks show the proportion of 100 pounds of the constituent in feed that may be saved in the manure. The slope at the top of each block represents the range of variation.

resulting from assimilation by the animal, takes place in the handling of the manure.

Results secured by the Ohio Experiment Station, showing the proportion of plant-food recovered from steers on cement and on earth floors, are given in Table XII.[19]

It should be noted that a larger percentage of the nitrogen and potassium of the feed was regained with the concrete floor, but there was little difference in the phosphorus. When one recalls the facts that more than 40 per cent of the nitrogen and 60 per cent of the potash occur in the liquid, and practically all the phosphoric acid is found in the solid, these results are not surprising.

Figure 122 shows the percentage of constituents recovered in the manure from horses and cows.[20] The variation in height of the black line indicates the great fluctuation in the proportion of the constituents that are returned to the soil through manure in actual farm practice. On the average farm, only about one-fourth the organic matter, one-third the nitrogen, and one-half the phosphorus and potassium of the feed are returned to the soil in the manure.

### 3. Plant-Food Lost from Exposed Manure

Plant-food is lost rapidly from manure exposed to the weather. The loss is due to the combined effects of fermentation and leaching. Fresh manure contains large numbers of bacteria which cause fermentation. As these bacteria decompose the manure, ammonia gas is formed, and may be lost into the atmosphere. When the stable has a strong ammonia odor one knows that nitrogen is being lost from the manure. When horse manure is stored in a loose pile, fungi may develop a condition known as *firefanging*. This type of fermentation produces a condition in which the manure heap is dry and gray in color. It develops very quickly, and is accompanied by a rapid loss of organic matter.

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[19] Thorne, "Farm Manures," p. 134. Orange Judd Co., New York.

[20] Cornell Reading Course Bul. 141.

When the decomposing manure is exposed to the weather, the loss of plant-food is increased by the leaching of the soluble material by rain. Many experiments have been conducted to determine the rate of loss in exposed manure. Table XIII gives the results of an experiment conducted at the Cornell Experiment Station, New York, in which both cow and horse manure were exposed over a period of five months beginning in late April.[21] The horse manure was untreated, but the cow manure had been treated with gypsum before exposure. The results secured in a similar Canadian experiment in which manure was exposed for six- and twelve-month periods are given in Table XIV.[22] In this experiment, an equal amount of the same quality of manure was put in proper storage over the same periods of time. Even though the rate of decomposi-

TABLE XIII

Loss from Manure Exposed for a Period of Five Months at Cornell Station, New York

| | Number of Pounds at Beginning of Experiment | | Number of Pounds at End of Experiment | | Percentage of Loss | |
|---|---|---|---|---|---|---|
| | Horse | Cow | Horse | Cow | Horse | Cow |
| Gross weight......... | 4000.0 | 10,000 | 1730.00 | 5125 | 57 | 49 |
| Nitrogen............ | 19.6 | 47 | 7.79 | 28 | 60 | 41 |
| Phosphoric acid...... | 14.8 | 32 | 7.79 | 26 | 47 | 19 |
| Potash.............. | 36.0 | 48 | 8.65 | 44 | 76 | 8 |

[21] Bul. 27, Cornell Exp. Sta., New York.

[22] Bul. 31 of Central Exp. Farm, Canadian Dept. of Agr.

tion and consequently the loss of organic matter were nearly as great in the exposed as in the unexposed manure, there was a marked reduction in the loss of all three plant-food constituents. The addition of preservatives, such as superphosphate, to manure where stored or where exposed to the weather may still further reduce the loss of nitrogen. Results from a recent experiment at the Cornell Experiment Station, in which manure was treated with superphosphate before exposure, indicate virtually no loss of phosphoric acid.

TABLE XIV

Loss from Manure During Exposure—Canadian Experiment

| | Percentage Loss in Six Months | | Percentage Loss in Twelve Months | |
|---|---|---|---|---|
| | Exposed | Stored | Exposed | Stored |
| Organic matter.......... | 65 | 58 | 69 | 60 |
| Nitrogen............... | 30 | 19 | 40 | 23 |
| Phosphoric acid......... | 12 | .. | 16 | 4 |
| Potash................. | 29 | 3 | 36 | 3 |

Recent investigations at the Vermont Experiment Station show a loss of as much as 50 per cent of the nitrogen content of manure as the result of freezing, and even a larger percentage when the manure is dried. The losses are relatively greater from cow than from horse and sheep manure. They are materially reduced, but not prevented, by the incorporation of superphosphate.

### 4. Amount of Manure Produced by Different Animals

In Table XV is given the average daily and yearly production of excrement per 1000 pounds of live weight of farm animals.

TABLE XV

DAILY AND YEARLY PRODUCTION OF MANURE—1000 POUNDS LIVE WEIGHT

| Kind of Animal | Pounds Solid Daily | Pounds Liquid Daily | Total Pounds Daily | Tons Yearly |
|---|---|---|---|---|
| Horse | 40 | 10 | 50 | 9.1 |
| Dairy cow | 50 | 20 | 70 | 12.7 |
| Fattening steer | 29 | 12 | 41 | 7.5 |
| Hogs | 48 | 34 | 82 | 15.0 |
| Sheep | 22 | 11 | 33 | 6.0 |
| Poultry | .. | .. | 23 | 4.3 |

### 5. ADDITIONAL BENEFITS OF MANURE

Benefits, other than those accounted for by the nitrogen, phosphoric acid, and potash furnished, may result from the application of farm manure. The organic matter materially aids in producing a good physical condition of the soil. This facilitates tillage, increases the water-holding capacity of the surface soil, and produces a condition favorable to the beneficial soil bacteria. Manure is known to contain large numbers of bacteria. When incorporated with the soil, these bacteria may prove of material benefit in increasing the rate at which the plant-food of the soil becomes available. Manure is slightly alkaline in character, and at least may temporarily lessen soil acidity and thereby benefit clover and alfalfa.

### 6. RESIDUAL EFFECT OF MANURE

The full benefit of farm manure is not secured on the first crop. It is known to be effective over a period of several years. This residual effect is less pronounced in warm climates and in sandy soil. The plant-food supplied by the urine becomes largely effective the first year, but that of the dung becomes available more slowly as the organic matter decomposes. Nitrogenous fertilizer materials, on the other hand, are largely effective the first year and are of very little benefit except to the crop for which they are applied. Land is not ordinarily manured more often than once in three or four years, except where cropped intensively and manure is purchased.

The marked residual effect of manure has been demonstrated at the Rothamsted Experiment Station in England, where for twenty consecutive years an application of over 15 tons to the acre was made for barley. At the end of this period the applications were discontinued. Although the yields of barley became less from year to year after the use of manure was discontinued, they remained higher for a period of twenty years than the original yields on the same soil without treatment.

### 7. Experimental Results with Manure

Many experiments have been conducted with manure in order to determine its effectiveness in increasing the yields of crops. Results of several of these experiments, which have been conducted for a sufficiently long period of time to furnish reliable information, are summarized in the following tables.

Manure has been applied at three different rates for a period of fifty years at the Pennsylvania Experiment Station. A rotation or corn, oats, wheat, and hay (clover and timothy) has been followed. Manure has been applied twice in the rotation at the rates of 6, 8, and 10 tons to the acre for corn and wheat. Average annual yields for the forty years and the estimated returns per ton of manure applied are given in Table XVI.[23]

At the Ohio Experiment Station fresh and exposed manure have been compared both with and without reinforcing materials in a three-year rotation of corn, wheat, and clover for a period of twenty-six years. Average annual yields and estimated returns per ton of manure are given in Table XVII.

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[23] Bul. 175, Pennsylvania Exp. Sta.

## TABLE XVI

### PENNSYLVANIA RESULTS WITH MANURE

| Rate Application Every Other Year | Crop Yields | | | | Value of Crop Increase per Ton of Manure* |
|---|---|---|---|---|---|
| | Bu. Corn | Bu. Oats | Bu. Wheat | Lbs. Hay | |
| 6 tons | 56 | 42 | 24 | 3804 | $2.63 |
| 8 tons | 55 | 43 | 25 | 4117 | 2.50 |
| 10 tons | 58 | 44 | 26 | 4225 | 2.19 |
| Untreated | 34 | 31 | 12 | 2189 | ..... |

* Crop values used in calculation: corn 60 cents a bushel, oats 40 cents a bushel, wheat $1 a bushel, and hay $10 a ton.

## TABLE XVII

### OHIO RESULTS WITH FRESH AND ROTTED MANURE

| Treatment | Yield | | | Value of Crop Increase per Ton of Manure |
|---|---|---|---|---|
| | Bu. Corn | Bu. Wheat | Lbs. Clover | |
| Fresh manure (8 tons) | 62 | 24 | 4151 | $3.55 |
| Exposed manure (8 tons) | 56 | 23 | 3655 | 2.92 |
| Fresh manure (8 tons) and superphosphate (320 lbs.) | 68 | 29 | 4897 | 5.00 |
| Exposed manure (8 tons) and superphosphate (320 lbs.) | 65 | 28 | 4466 | 4.42 |
| Fresh manure (8 tons) and rock phosphate (320 lbs.) | 67 | 27 | 4675 | 4.30 |
| Exposed manure (8 tons) and rock phosphate (320 lbs.) | 65 | 30 | 4388 | 3.59 |
| Unmanured | 37 | 14 | 2943 | .... |

## TABLE XVIII

### OHIO EXPERIMENT—APPLICATION OF MANURE

| Crops Manured | Average Annual Increase in Yield | | | | Value of Crop Increase per Ton of Manure |
|---|---|---|---|---|---|
| | Bu. Corn | Bu. Oats | Bu. Wheat | Lbs. Clover | |
| Corn and wheat, ½ each | 13 | 5 | 9 | 481 | $1.86 |
| All on corn | 15 | 8 | 7 | 415 | 1.79 |
| All on wheat | 9 | 4 | 12 | 1105 | 2.24 |
| All on clover | 9 | 2 | 2 | 1192 | 1.09 |

## TABLE XIX

### WISCONSIN EXPERIMENT—APPLICATION OF MANURE

| Crops Manured | Yield, Eight-Year Average | | | | Value of Crop Increase per Ton of Manure |
|---|---|---|---|---|---|
| | Bu. Corn | Bu. Oats | Bu. Wheat | Tons Clover | |
| 16 tons corn, plowed under | 65 | 58 | 29 | 4.3 | $1.19 |
| 16 tons clover, top-dressing | 61 | 56 | 28 | 4.6 | 1.11 |
| 8 tons corn<br>8 tons wheat } plowed under | 67 | 54 | 34 | 4.4 | 1.58 |
| 8 tons corn<br>8 tons wheat } top-dressing | 65 | 56 | 35 | 4.4 | 1.48 |
| 8 tons corn, plowed under<br>8 tons clover, top-dressing | 64 | 54 | 27 | 4.3 | .97 |

In another experiment at the Ohio Station, manure has been applied to different crops in a four-year rotation of corn, oats, wheat, and clover.[24] The rate of application has been 8 tons to the acre once in the rotation. In addition, a 480-pound application of superphosphate has been applied with each 8 tons of manure. The average annual increases in yields resulting from the superphosphated manure are given in Table XVIII. The table includes an estimate of the returns per ton of manure after the cost of superphosphate has been deducted.

Results from a similar experiment at the Wisconsin Station are given in Table XIX.[25]

## COMMUNITY STUDIES

Visit several well-managed livestock farms in the community and secure information as to how the manure supply is handled and for what crops it is used.

1. Is the liquid manure efficiently saved?
2. What bedding material is used?
3. Is the manure hauled directly to the field or put in storage?
4. If stored, is it placed in a properly constructed pit or shed?
5. Is the manure treated with superphosphate or rock phosphate?
6. Is the farm equipped with a manure spreader?
7. For what crops is the manure applied?
8. What is the rate of application?

## PROBLEMS

1. How much manure, including bedding, would be produced annually by the following livestock:

| | | | |
|---|---|---|---|
| 4 work horses weighing | 1250 | pounds | each |
| 10 dairy cows weighing | 900 | " | " |
| 8 hogs weighing | 250 | " | " |
| 40 sheep weighing | 125 | " | " |
| 125 chickens weighing | 4 | " | " |

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[24] Ohio Exp. Sta. Bul. 362.

[25] "Fertility and Crop Production," S. F. Hinkle, p. 75.

2. Disregarding the bedding, how much nitrogen, phosphoric acid, and potash would be produced annually in the solid and liquid excrements of a 1000-pound dairy cow? How many tons of a 2-8-2 fertilizer would be required to furnish an equivalent amount of nitrogen?[26]

3. How much manure would be produced annually on a farm where the dry matter in the feed amounts to 7.5 tons and that in the bedding to 2.3 tons monthly?

4. If manure containing 80 per cent water sells for $1.50 a ton, what would a ton of manure containing 60 per cent of water be worth?

5. If half the liquid from cow manure is lost by leaching, what would be the per cent of nitrogen and of potash lost from the combined solid and liquid excrement? (Refer to Tables VIII and IX.)

6. On the basis of Cornell Station results (see Table XIII), calculate the weight of a mixture of 2 tons of horse manure and 20 tons of cow manure, after being exposed for 5 months.

7. Calculate the value of crop increase per ton of superphosphate when it is used in addition to fresh manure. Use Ohio Experiment Station results (Table XVII).

8. On the basis of the average of the results of the Ohio and Wisconsin Stations (Tables XVIII and XIX), how much more a ton is manure worth when applied for corn than when used for top-dressing clover?

## REFERENCES

### Experiment Station Publications

Artificial Manure Production. Mo. Bul. 369.
Concerning Farm Manures. Vt. Bul. 206.
Farm Manures. S. C. Ext. Bul. 92.
Manure Increases Farm Income. Ind. Bul. 398.
Save Plant Food in Manure. Wis. Cir. 297.
Value and Care of Farm Manure. Mich. Bul. E71.

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[26] A 2-8-2 fertilizer is one containing 2 per cent nitrogen, 8 per cent phosphoric acid, and 2 per cent potash. See page 304.

# CHAPTER VI

## LIMING

Most crops grow best on soils that are well supplied with lime. Many of the more prosperous agricultural areas have soils of limestone origin, and it is seldom that a really profitable agriculture has been developed in a section of extremely acid soils. When, as a result of insufficient lime, the surface soil is strongly acid, lime can almost always be applied with profit.

FIG. 123. A LIMESTONE VALLEY IN PENNSYLVANIA. (Agronomy Dept., Pa. State Col.)

Many of the more prosperous agricultural areas have soils of limestone origin, and it is seldom that a really profitable agriculture has been developed in a section of extremely acid soils.

It is a well-known fact that farmed soils tend to become acid. This is especially true in humid regions where lime is

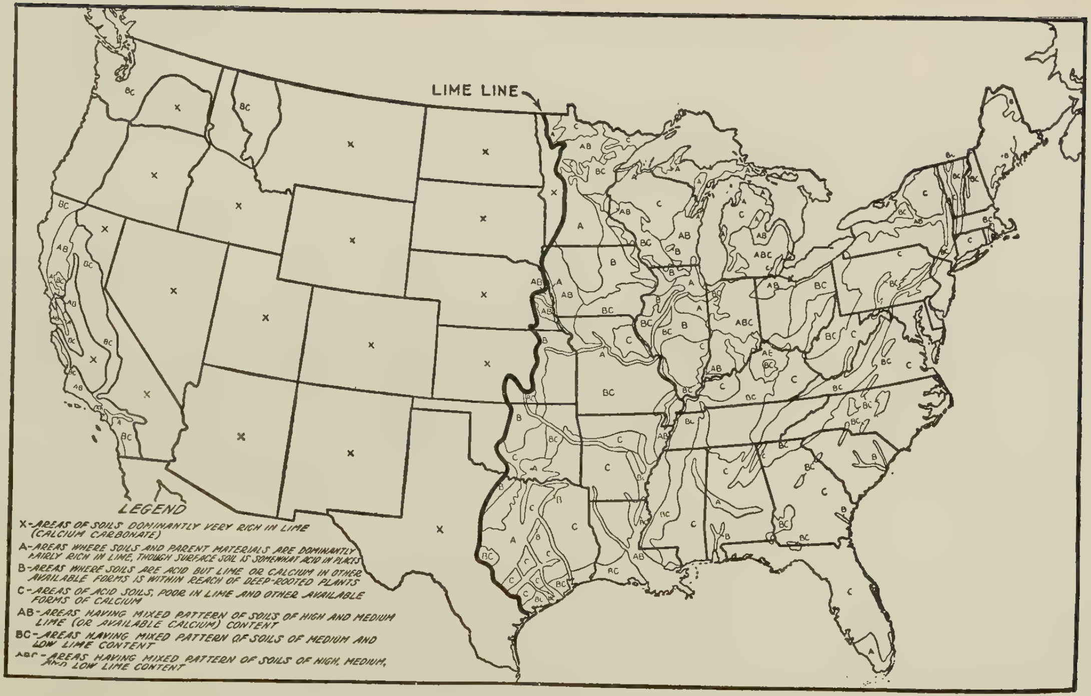
LIME LINE
LEGEND
X-AREAS OF SOILS DOMINANTLY VERY RICH IN LIME (CALCIUM CARBONATE)
A-AREAS WHERE SOILS AND PARENT MATERIALS ARE DOMINANTLY FAIRLY RICH IN LIME, THOUGH SURFACE SOIL IS SOMEWHAT ACID IN PLACES
B-AREAS WHERE SOILS ARE ACID BUT LIME OR CALCIUM IN OTHER AVAILABLE FORMS IS WITHIN REACH OF DEEP-ROOTED PLANTS
C-AREAS OF ACID SOILS, POOR IN LIME AND OTHER AVAILABLE FORMS OF CALCIUM
AB-AREAS HAVING MIXED PATTERN OF SOILS OF HIGH AND MEDIUM LIME (OR AVAILABLE CALCIUM) CONTENT
BC-AREAS HAVING MIXED PATTERN OF SOILS OF MEDIUM AND LOW LIME CONTENT
ABC-AREAS HAVING MIXED PATTERN OF SOILS OF HIGH, MEDIUM, AND LOW LIME CONTENT

FIG. 124. RELATIVE LIME CONTENT AND ACIDITY OF SOILS OF THE UNITED STATES. (Farmers' Bul. 1845, U. S. Dept. of Agr.)

Areas characterized as having soils of high-, medium-, and low-lime content usually need the application, respectively, of very small, moderate, and comparatively large quantities of lime. Note the *lime line* dividing the lime-accumulating soils from those likely to be deficient in lime.

constantly leached from the soil and carried away in the drainage waters. As a result, the well water of sections where the soils are rich in lime is invariably extremely hard. Crops take lime from the soil, and, particularly where sold from the farm, reduce the soil supply of this valuable constituent. Measurements made of the rate of loss show that, under normal climatic conditions, a soil well supplied with lime loses 300 to 500 pounds of calcium and magnesium carbonate to the acre annually. To replace this loss, a ton of limestone or its equivalent of some other form of lime must be supplied every four or five years.

The need for lime is dependent to a large extent on rainfall. It is in the eastern half of the United States that soils almost everywhere require liming, though even in this section there are some soils which do not need it. Some areas on the Pacific Coast have soils which are moderately acid. In Fig. 124 is shown the general location of soils well supplied with lime and those of varying degrees of acidity.

The extensive need for lime in the southeastern states is strikingly illustrated by the results of the soil-testing work done in South Carolina where over two million acidity determinations were made of soil samples taken on 95 per cent of the farms of the State. The results are recorded in Table XX.

Lime is not a real fertilizer. It supplies neither nitrogen, phosphoric acid, nor potash, and cannot replace commercial fertilizer or manure. Too often it has been considered a "cure-all," capable of supplying the various requirements for the continued production of large yields. In reality, its chief function is to reduce soil acidity. Some beneficial effect may result from the calcium or the magnesium functioning as plant nutrients. Although lime alone will neither maintain nor materially improve run-down soils, any practical scheme of permanent soil improvement must include liming as one of its essentials.[1]

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[1] See General Information at end of chapter for chemistry of lime.

TABLE XX

Summary of $p$H Values of South Carolina Soil Samples

| Degree of Acidity | Arbitrary $p$H Value Range | Percentage | |
|---|---|---|---|
| | | Each Class | Cumulative |
| Extremely acid............ | Below 4.51 | 1.55 | ......... |
| Very strongly acid......... | 4.51–4.75 | 3.07 | 4.62 |
| | 4.76–5.00 | 6.70 | 11.32 |
| Strongly acid.............. | 5.01–5.25 | 12.25 | 23.57 |
| | 5.26–5.50 | 17.81 | 41.38 |
| Moderately acid........... | 5.51–5.75 | 20.00 | 61.38 |
| | 5.76–6.00 | 19.19 | 80.57 |
| Slightly acid.............. | 6.01–6.50 | 16.74 | 97.31 |
| | 6.51–7.00 | 2.23 | 99.54 |
| Alkaline.................. | Above 7.00 | 0.45 | 100.00 |

**Operations:**

1. Determining the need for lime.
2. Selecting the kind of lime to use.
3. Applying lime.

## 1. Determining the Need for Lime

By the term *lime requirement* is meant the amount of lime necessary to reduce, to a point favorable for the crop or crops grown, the acidity in the plowed soil of an acre. While crops vary in their need for lime, it has been found that most of them grow best in a soil that is slightly acid to neutral in character. In practice, the surface soil should be maintained at or near neutrality for most crops. Even though many crops may do best where the soil is very slightly acid, it is impracticable to produce and maintain an absolutely uniform soil reaction throughout a given field. In general farming the aim should be to supply sufficient lime to satisfy, over the field as a whole, the needs of clover or any other lime-loving crop grown in the rotation.[2]

**Procedure:**

A. Supply the lime needs for alfalfa and clover.
B. Consider the lime needs of other crops.
C. Avoid overliming.
D. Determine the acidity of the soil.

**A. Supply the lime needs for alfalfa and clover.** The failure of legumes, especially alfalfa and clover, is often due to insufficient lime. Success with legumes is essential for the most profitable production of the other crops in the rotation, and it will be found that farms are seldom abandoned so long as clover grows well on them. One of the first essentials in the improvement of depleted soils is to furnish the treatment that will insure success with clover. The importance of

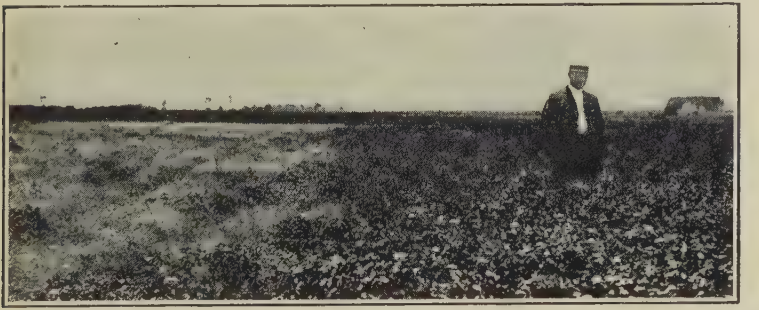

FIG. 125. UNLIMED AND LIMED CLOVER. (Agronomy Dept., Ill. Agr. Exp. Sta.)

The failure of legumes, especially alfalfa and clover, is often due to insufficient lime.

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[2] See General Information at end of chapter for the benefits of lime.

legumes in the improvement of poor soils, or in fact, in maintaining good ones, cannot be overemphasized.[3]

Legume crops in general are in greater need of lime than the non-legumes. Even though some legumes will grow in a distinctly acid soil, they invariably grow better in such soil when lime is applied. Those having a high lime requirement, such as alfalfa, sweet clover, and red clover, have been found to be particularly efficient in improving the crops that follow, through increasing the supply of available nitrogen in the soil.

Fig. 126. A Field of Red Clover.

Success with legumes is essential for the most profitable production of the other crops in the rotation. Farms are seldom abandoned so long as clover grows well on them.

The use of lime in field-crop production should be based largely on the need of the legumes grown. Just so long as alfalfa or clover grows well, lime need not be applied. Where they show signs of failure or even a material reduction in yield, test the soil and, if it is found acid, apply lime. A liming practice based on supplying the lime needs of the legume crops is economically sound on grain and livestock farms.

[3] See Chapter VIII for information on leguming land.

**B. Consider the lime needs of other crops.** Since lime is needed most by legume crops, its primary value to the grain and grass crops comes from improving the legumes, and thus enabling them to increase the available nitrogen supply of the soil. Nevertheless, lime may be directly beneficial to certain of the cereal and grass crops. Most vegetable crops respond to lime when the soil is strongly acid. Some crops, however, do best on distinctly acid soils. For them lime is injurious. Consider the relation of the individual crops to degrees of soil acidity or alkalinity in determining the liming practice.

FIG. 127. CORN ON ALFALFA SOD.

Since lime is needed most by legume crops, its primary value to the grain and grass crops comes from improving the legumes, and thus enabling them to increase the available nitrogen supply of the soil.

In Table XXI crops are classified on the basis of their requirement for lime and their tolerance to soil acidity.[4]

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[4] See General Information at end of chapter for explanation of *p*H.

Although this classification, based on the greatest intensity of acidity under which satisfactory yields of the different crops can be secured, is of value, it should be remembered that in practical farming the rotation rather than the individual crops must be considered. With wheat, for example, the acidity may be as great as $p$H 5.5 without reducing the yield. For profitable production the crop must be grown in a rotation

### TABLE XXI

Grouping of Crops Based on Tolerance to Soil Acidity

For satisfactory yields acidity should not be in excess of $p$H stated

| 1. Slight $p$H 6.5 | 2. Moderate $p$H 6 | 3. Medium $p$H 5.5 | 4. Strong $p$H 5 | 5. Very strong $p$H 4.5 |
|---|---|---|---|---|
| Alfalfa | Peanuts | Alsike clover | Vetch | Blueberries |
| Sweet clover | Crimson clover | Cowpeas | Buckwheat | Cranberries |
| Sugar beet | Red clover | Soybeans | Canada bluegrass | Citrus fruits |
| | Barley | White clover | Carpet grass | Rhododendron |
| | Kentucky bluegrass | Corn | Redtop | Strawberry |
| | Asparagus | Cotton | Bent grass | Watermelon |
| | Beets | Oats | Rye | |
| | Brussels sprouts | Timothy | Tobacco | |
| | Cabbage | Wheat | Potatoes | |
| | Carrots | Cantaloupe | Poverty grass | |
| | Cauliflower | Lima bean | Apples | |
| | Celery | Peas | Grapes | |
| | Chard | Tomatoes | Peaches | |
| | Cucumber | Lespedeza | Pears | |
| | Lettuce | Millet | Plums | |
| | Onions | Sudan grass | | |
| | Parsnips | Sorghum | | |
| | Peppers | | | |
| | Radish | | | |
| | Spinach | | | |
| | Squash | | | |

with a legume, which is most commonly red clover or alfalfa, either one of which is less tolerant to acidity than wheat. The liming practice for the rotation should be based on the needs of the clover, or the alfalfa crop. Invariably the least-tolerant crop of the rotation determines the most favorable soil reaction for the rotation as a whole.

The crops in the third group would produce as well or even better with a soil reaction of $p$H 6 or even $p$H 7, and those in the fourth group having a tolerance of $p$H 5 should produce as well at $p$H 6 or even $p$H 6.5. The potato crop might be considered an exception if quality is considered, because when the soil acidity is reduced much below $p$H 5 potato scab may injure the quality of the tubers. In practical production, most of the other crops in group 4 can be produced more profitably on soil less acid than $p$H 5.

The crops listed in group 5 are not only tolerant to acidity, but even require strongly acid soils for their normal growth. In their production, lime should not be applied.

**C. Avoid overliming.** Since most crops grow best in a soil that is slightly acid, care should be exercised not to apply lime in amounts to produce an alkaline condition; certainly the reaction should never be greatly in excess of $p$H 7 except for the control of such diseases as clubroot of cabbage and cauliflower. Normally, soils used for the production of low-value field crops are not overlimed, but occasionally lime is applied to such soils when it is not needed. However, in connection with the production of high-value crops, where the cost is of minor importance, injury often results from either too heavy or too frequent applications of lime. Such injury most often occurs in home flower and vegetable gardens, in greenhouses, and on lawns. Excessive applications of wood ashes frequently result in crop injury.[5]

**D. Determine the acidity of the soil.** An acid condition of the soil can usually be detected by the character of the vegetation. Certain weeds, such as sheep sorrel, paint brush, and buckhorn, are very tolerant to acidity and persist on soils too sour to grow clover and timothy. Consequently, their presence in hay fields indicates that the surface soil at least is becoming acid. Where a seeding of alfalfa and clover gives only clover, the failure of the alfalfa may generally be attributed to acidity, provided the soil is well drained and the alfalfa seed sufficiently hardy for the locality. Likewise, where redtop does better than timothy, and where the bent grasses or poverty grass replace Kentucky bluegrass and white clover in permanent pastures, one may conclude that the soil may be deficient in lime. Study the character and growth of vegetation, both crops and weeds, and watch for indications of the development of sufficient acidity to cause injury to the least-tolerant crop in the rotation.

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[5] See General Information at end of chapter for information on injury from excessive liming.

Before deciding on a liming program, test the soil for acidity. This is the best way to make certain that the soil is acid and to determine the amount of lime that should be applied. There are several reliable methods of testing soils for acidity. Of these, the litmus-paper test is the simplest. With it one can tell whether or not the soil is strongly acid, but the degree of acidity cannot be determined accurately. All that is needed for the test is a supply of fresh blue litmus paper and a small amount of rain water. To make the test, take a small handful of surface soil, moisten slightly with rain water, and mold into a ball. Break it open and insert one end of a strip of blue litmus paper, then close the ball, pressing the moistened soil firmly against the litmus paper. After ten minutes open the ball, remove the litmus paper, and wash it with the rain water. If the end of the paper that has been in contact with the soil has turned red or pink, the soil is very acid; if unchanged in color, the soil is neutral, or at most only mildly acid.[6]

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[6] See General Information at end of chapter for directions for taking soil samples, for making a lime-requirement map, and for more accurate methods of testing soils for acidity.

If the blue litmus paper has not changed in color, pour a little dilute hydrochloric acid on samples of the surface soil to determine whether it is alkaline. If it is, the acid will bubble. Although an alkaline condition of the surface soil is undesirable for many crops, an excess of lime carbonate in the subsoil is desirable in the production of either alfalfa or clover. When either of these legumes is grown in the rotation, test the subsoil to a depth of 3 feet with hydrochloric acid.

### 2. Selecting the Kind of Lime to Use

The three important forms of lime used in the treatment of soils are *ground limestone, burned lime,* and *hydrated lime.* Although they differ in their acidity-correcting value, they all function similarly and when applied in proper amounts to acid soils will benefit the growth of crops, particularly the legumes. The form to use depends largely on price. In order to determine the most economical kind of lime to use, it is necessary to understand the composition of the different forms. Other factors, such as fineness, availability, and agreeableness of handling, must be considered.[7]

**Procedure:**

A. Consider the advantages of carbonate forms of lime.
B. Consider the advantages of burned and hydrated lime.
C. Determine the relative value of different forms of lime.
D. Consider the guaranteed analysis and price.
E. Select the liming material.

**A. Consider the advantages of carbonate forms of lime.** Limestone is the source of practically all agricultural lime. It occurs as a common rock in many sections of the country, and the lime in it occurs as calcium, or calcium and magnesium in the form of carbonates. If the magnesium content is high the stone is known as *dolomite* or *dolomitic limestone.*

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[7] See General Information at end of chapter for composition of different forms of lime.

Both calcium and magnesium carbonates neutralize acidity. Magnesium carbonate is the stronger of the two, 84 pounds correcting as much acidity as 100 pounds of calcium carbonate, but it is not so readily available. In practice, it is generally assumed that the value of magnesium carbonate is equal to, if not greater than, that of calcium carbonate. The *total carbonate* content of limestone consists of the sum of the calcium and the magnesium carbonate. Most limestones contain magnesium as well as calcium, but some consist almost entirely of calcium carbonate. In addition to the carbonates, they contain more or less clay and other impurities. Most of the stone that is ground or burned for agricultural use contains over 90 per cent of total carbonates. The better grades of finely pulverized limestone contain 95 to 99 per cent of combined calcium and magnesium carbonates.

FIG. 128. A LIMESTONE QUARRY.

Limestone is the source of practically all agricultural lime. It occurs as a common rock in many sections of the country.

(1) *Ground limestone.* This is one of the most agreeable forms of lime to handle. Whereas both the burned and hy-

drated lime are caustic and will burn the skin, particularly in warm weather, the limestone is harmless and can be handled freely the same as any other ground rock. It is partly because of this desirable feature that ground limestone is so extensively used by farmers.

The effectiveness of limestone depends not alone on composition but also on fineness of grinding. The fineness is expressed in terms of the mesh size of the finest sieve through which all the material will pass. For example, by *10-mesh limestone* is meant material ground to such a degree of fineness that all of it will pass a sieve having 10 meshes to the linear inch. Much of the material in this 10-mesh grade will pass through a screen having 20, 80, and even 100 meshes to the linear inch.

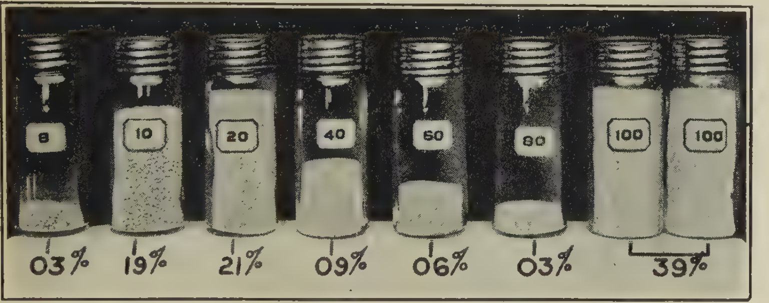

Fig. 129. A Sample of Ground Limestone Separated into Different Grades of Fineness.

**The effectiveness of limestone depends not alone on composition but also on fineness of grinding.**

Limestone particles passing a 50- or 60-mesh sieve will largely become effective the first year. Those coarser than this are slower in action but more lasting in their effect on the soil. Though the recommendation relative to fineness varies somewhat in different states, agricultural workers are fairly well agreed that either the 10- or 20-mesh stone will give satisfactory results. At least 90 per cent of the product should pass a 20-mesh and 50 per cent should pass a 100-mesh sieve.[8]

(2) *Screenings.* When limestone is ground to be used in road construction, it is commonly passed over a 3- to 4-mesh sieve. The material passing through the sieve is called *screenings.* This coarse grade of limestone is used in some sections for liming land. Because of the high content of coarse material, much heavier applications are necessary. Use this grade only when the price is sufficiently lower than that of fine grades of limestone, or of burned or hydrated lime, to give more economical returns per dollar invested.[9]

FIG. 130. A MARL DEPOSIT.

Deposits of marl occur in many of the northern states and have been utilized to some extent as a local source of agricultural lime.

(3) *Marl.* The term *marl* is applied to soft, chalky calcium carbonate. Deposits of this material occur in many of the northern states and have been utilized to some extent as a local source of agricultural lime. These deposits are largely

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[8] See General Information at end of chapter for experimental results with limestone of different grades of fineness.

[9] See General Information at end of chapter for lime value of gypsum and ashes.

confined to swampy areas, and the cost of digging and drying the marl is often too great to justify its extensive use. Marl is similar in composition to limestone. The commercial grades contain 90 per cent or more of calcium carbonate. The material generally sells at a higher price than ground limestone, even though it is of no great agricultural value. Local marl deposits may sometimes be utilized to advantage.

(4) *Oyster shells.* Oyster shells constitute another source of the carbonate form of lime. They contain 90 to 95 per cent calcium carbonate. Their use in liming soils has been confined largely to the Atlantic seaboard. Both the ground and burned shells are used, but the screenings from the grinding of shells for poultry is the main commercial source today. This by-product material contains about 90 per cent calcium carbonate and is of about the same agricultural value as ground limestone and marl.

(5) *Slag.* Slag, a by-product in the manufacture of pig iron, is of value as a liming material. In this product the calcium occurs as a silicate. It is generally considered inferior to the better grades of limestone, and should be used only if the price is sufficiently low to make it an economical source of lime. Some slag contains phosphorus, and has a fertilizing value in addition to its lime value. There are various other by-product forms of lime, such as tanner's waste, button dust, and sugar-factory sludge, but they are all of local interest only.[10]

(6) *Limestone storage bins.* In communities where bulk limestone is extensively used, there is need for local storage bins. They should be constructed on the railroad so that the limestone can be unloaded when it arrives and kept dry until the farmers are ready to haul and apply it to their land. The construction of a lime-storage bin is a good coöperative project for any community where lime is needed.

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[10] See Chapter VII for fertilizer value of phosphatic slag.

(7) *Grinding limestone on the farm.* Where a good quality of limestone occurs on the farm or in the immediate vicinity, it may be ground with a small portable crusher. Several makes of farm pulverizers are on the market. They can be operated with the ordinary farm tractor and have a rated capacity of 1 to 2 tons per hour. The cost of quarrying and grinding has been found to vary \$2 to \$3 or more a ton. These small crushing outfits appear to be best suited to sections which are somewhat remote from the railroad and in which limestone outcrops occur. Under these conditions, home grinding should be considered. Limestone is sometimes burned on the farm, but the practice cannot be recommended for general use.

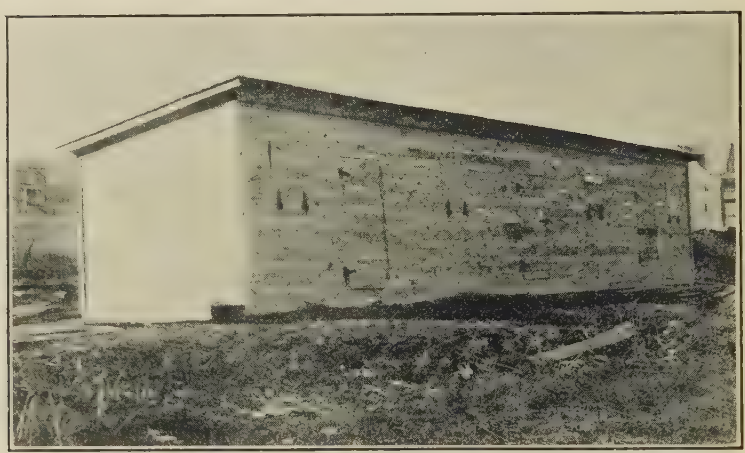

FIG. 131. LIMESTONE STORAGE SHED. (Michigan Limestone Co., Buffalo.)

The construction of a lime-storage bin is a good coöperative project for any community where lime is needed.

**B. Consider the advantages of burned and hydrated lime.** When limestone is burned, carbon dioxide gas, $CO_2$, is given off. The calcium and magnesium carbonates, $CaCO_3$ and $MgCO_3$, are changed to the oxides, $CaO$ and $MgO$. One hundred pounds of chemically pure calcium carbonate, when burned, will give off 44 pounds of carbon dioxide and produce 56 pounds of calcium oxide. The 56 pounds of pure burned lime are equivalent to the original 100 pounds of limestone in neutralizing soil acidity.

Hydrated lime is made by adding water to the burned lime. The calcium and magnesium oxides change to the hydroxides, $Ca(OH)_2$ and $Mg(OH)_2$. In the case of calcium oxide, 56 pounds unite with 18 pounds of water, forming 74 pounds of calcium hydroxide which has exactly the same acidity-correcting value as the original 100 pounds of calcium limestone or the 56 pounds of burned lime. When the burned lime is exposed to the air, it reabsorbs the carbon dioxide from the air and changes back to the carbonate form. The product is known as *air-slaked lime,* and has the same neutralizing power as the original limestone.

FIG. 132. GRINDING LIMESTONE ON THE FARM.

Where a good quality of limestone occurs on the farm or in the immediate vicinity, it may be ground with a small portable crusher.

The relative value of the three common forms of lime is given in Table XXII. These figures are based on chemically pure materials, and it is assumed that, in practice, magnesium compounds are equal in value to those of calcium.

Hydrated lime is of very fine consistency, and is commonly shipped in paper sacks. The burned lime is sometimes ground and bagged, but is also shipped unground in bulk. In this form it is often spoken of as *lump lime* and is shipped only in carload lots. Both the hydrated and the ground, burned lime can be applied readily with the lime distributor, but the lump lime must be slaked before it can be applied to the land satisfactorily. The common procedure is to distribute lump lime over the field in small piles and leave it thus exposed until it slakes. It is then scattered with a shovel. A better method is to place it in a large pile and, after it has been slaked by exposure, distribute it with a manure spreader.

### TABLE XXII

### Value of Different Forms of Lime

| Kinds of Lime | Pounds Equivalent to 100 Pounds of Pure Limestone | Pounds Equivalent to 1 Ton of Pure Limestone | Comparative Ton Value Based on $3 per Ton for Limestone |
|---|---|---|---|
| Limestone | 100 | 2000 | $3.00 |
| Hydrated lime | 74 | 1480 | 4.05 |
| Burned lime | 56 | 1120 | 5.36 |

When distributed with a spreader and promptly harrowed into the surface soil, both the hydrated and the ground, burned lime become effective very quickly. They change back to the carbonate form almost immediately after they are distributed; but, on account of the extreme fineness of division, they act somewhat more quickly than the ordinary grades of limestone. However, limestone when finely ground becomes active the season it is applied, which fulfills all practical requirements for effectiveness. When the burned lime is slaked in piles, it may form a crust which breaks into lumps when the lime is applied. These lumps may remain intact in the soil for several years before they disintegrate and become effective. Hydrated lime should be applied when the soil surface is dry, and harrowed into the soil before a rain; otherwise, it will form a crust, which breaks down very slowly when incorporated with the soil.

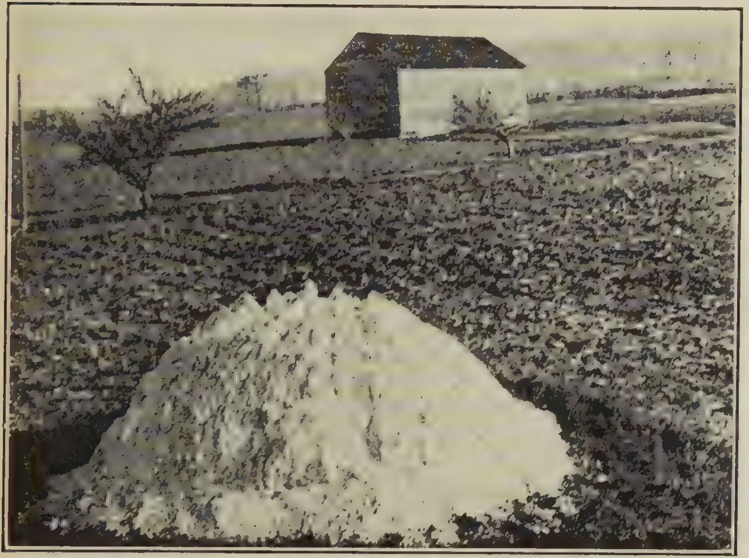

FIG. 133. SLAKING LUMP LIME. (Agronomy Dept., N. Y. State Col. of Agr.)

Lump lime must be slaked before it can be applied to the land satisfactorily. The common procedure is to distribute it over the field in small piles and leave it thus exposed until it slakes.

**C. Determine the relative value of different forms of lime.** In order to purchase lime to best advantage, one must be able to determine which of several forms or sources of lime is the cheapest. By taking into consideration the calcium or calcium and magnesium content, the purity, the freight, and the cost of hauling to the farm and applying to the land, it is possible to calculate the cheapest of several available sources of liming materials. Assume that a farmer living 5 miles from a freight station can purchase liming materials F.O.B. shipping point at the following figures:

Ground limestone, 98 per cent total carbonates, \$3 a ton, \$1.25 freight
Ground burned lime, 95 per cent calcium oxide, \$10 a ton, \$2 freight
Hydrated lime, 90 per cent calcium hydroxide, \$12 a ton, \$1.50 freight

The cost of hauling and distributing amounts to \$1.00 a ton. With this information available, the cheapest of the three forms of lime can be determined in the following manner:

(1) Determine the delivered cost by adding the freight to the quoted price at point of shipment.

\$ 3.00 + \$1.25 = \$ 4.25 delivered cost of limestone
\$10.00 + \$2.00 = \$12.00 delivered cost of burned lime
\$12.00 + \$1.50 = \$13.50 delivered cost of hydrated lime

(2) Determine the cost of a ton of each kind of lime applied to the field, by adding \$1.00 a ton.

\$ 4.25 + \$1.00 = \$ 5.25 cost of ton of limestone applied to land
\$12.00 + \$1.00 = \$13.00 cost of ton of burned lime applied to land
\$13.50 + \$1.00 = \$14.50 cost of ton of hydrated lime applied to land

(3) Determine the pounds of calcium oxide secured in a ton of each kind of lime.

98 per cent of 2000 = 1960 pounds $\times \frac{56}{100}$ = 1097 pounds calcium oxide
95 per cent of 2000 = 1900 pounds = 1900 pounds calcium oxide
90 per cent of 2000 = 1800 pounds $\times \frac{56}{74}$ = 1362 pounds calcium oxide

(4) Determine the cost of 2000 pounds of calcium oxide in each kind of lime.

$\frac{2000}{1097} \times \$\,5.25 = \$\,9.57$ cost in limestone
$\frac{2000}{1900} \times \$13.00 = \$13.68$ cost in burned lime
$\frac{2000}{1362} \times \$14.50 = \$21.29$ cost in hydrated lime

The limestone in this case is the cheapest, and the hydrated lime the most expensive. In this same way, the cheapest source of lime can be determined by the same method for other compositions and prices. If the burned or the hydrated lime, contains any material amount of magnesium, credit it with additional acidity-correcting value, by multiplying the magnesium oxide by the fraction $^{100}/_{84}$ and adding the result to the content of calcium oxide, thereby securing a figure representing the calcium oxide equivalent.

**D. Consider guaranteed analysis and price.** In most states lime manufacturers are required by law to furnish a guarantee of composition of their product similar to that required of fertilizer manufacturers.[11] A guarantee of fineness of limestone is also required in many states. With information relative to the composition of the available forms of lime as furnished in the guaranteed analysis, and with local delivered prices, the liming material can be judiciously selected for the individual farm.

**E. Select the liming material.** Consider the composition of the different forms of lime available for use in the community. Take into consideration the agreeableness of handling and the relative availability. In comparing the different sources of ground limestone consider the fineness of grinding. Finally, compare prices and buy the form of lime which, other things being equal, furnishes at the farm the greatest acidity-correcting or neutralizing value per dollar invested.

## 3. APPLYING LIME

Where needed, lime should usually be applied once in the rotation. This would normally be once every three to five years, but if a longer rotation is followed, an additional application of lime may be found desirable.

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[11] See Chapter VII for explanation of guaranteed analysis and sample fertilizer and lime law.

**Procedure:**

A. Lime at the proper time.
B. Apply at the proper rate.
C. Apply in the proper way.
D. Establish a definite liming practice.

**A. Lime at the proper time.** Lime may be applied either in the spring or in the fall Since most plowing is done in the spring, this is the normal season for applying lime. The objection to spring liming is that it may cause delay in the seeding of the spring crops. Also, the roads are often in poor condition for hauling at this season. Where the land to be limed is fall-plowed, apply the lime immediately after plowing. The lime remaining over winter in contact with the soil particles will have become fully effective before the spring planting. In the South, apply during the winter if the fields are plowed and sufficiently dry to permit harrowing. For spring liming, make the application just as early in the season as possible. Where clover or alfalfa is to be seeded, it is very essential that the lime be applied at least several weeks prior to seeding the legumes.

**B. Apply at the proper rate.** Lime should ordinarily be applied once in the rotation. If the lime requirement is not great, make the initial application sufficient to satisfy the needs of the surface soil to plow depth, taking into consideration the tolerance to acidity of the crops to be grown. In some places the lime requirement is so high that the cost of sufficient lime to satisfy it is prohibitive. Some benefit will be secured under such conditions from the use of relatively light applications, provided the lime is applied just prior to the seeding of the clover so that it will be concentrated in the surface inch or two of soil. Until you can afford to supply sufficient lime for the crops grown, change the cropping system and grow crops which are more tolerant to acidity.

For best results, use lime in sufficient quantity approximately to neutralize the acidity in the plowed soil. This is essential for alfalfa and sweet clover, and probably necessary for the best results with red and white clover as well as with Kentucky bluegrass. Except where acid-loving crops are to be grown, or potatoes, there is little danger of permanent injury, provided the lime is well incorporated with the soil and the rate of application is not greatly in excess of the amount necessary to neutralize the surface soil. After the lime requirement has been adequately met, apply a ton of ground limestone or an equivalent amount of burned or hydrated lime once every four or five years.[12] In liming permanent pastures, the rate of application need seldom exceed one ton of ground limestone, or its equivalent, to the acre.[13]

**C. Apply in the proper way.** Apply lime broadcast to the field, and do not put it in the row with the seed. Make the application after plowing rather than before. Harrow or disk the field thoroughly after the lime has been distributed in order to mix it with the top soil. The temporary injurious results which sometimes follow the heavy application of lime can usually be avoided by thoroughly incorporating the lime with the plowed soil. When the application is in excess of a ton and a half of ground limestone, or its equivalent, to the acre, apply half of it before plowing.

When liming is adopted as a regular practice, which it should be on grain and hay farms where the soil needs lime for alfalfa or clover, a lime distributor is an essential part of the machinery equipment. With it, any of the pulverized forms of lime can be spread advantageously. The manure spreader can be used for distributing lime. Place a little straw or manure in the bottom to prevent the lime from sifting between the slats of the apron. The rate of application can be controlled by the thickness of the layer of lime placed in the spreader, as well as by the regulation of the spreader itself. In general, applying by hand with a shovel is unsatisfactory.

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[12] See General Information at end of chapter for methods of determining the amount of lime needed.

[13] See Chapter X for information on liming permanent pastures.

It is very difficult to get a uniform distribution without making an unduly heavy application.

Lime may be applied the same year as manure or fertilizer, but, except under special conditions, it should not be mixed with these materials. Where manure is being applied the same year, broadcast it before plowing, and plow it into the soil.

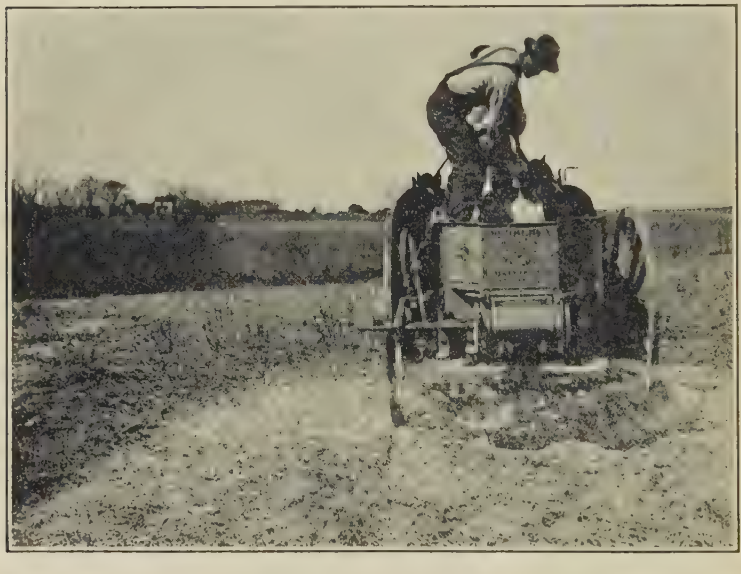

Fig. 134. Applying Limestone with Endgate Distributor. (Holden Co., Peoria, Ill.)

**When liming is adopted as a regular practice, which it should be on grain and hay farms where the soil needs lime for alfalfa or clover, a lime distributor is an essential part of the machinery equipment.**

Apply the lime to the manured land after it has been plowed. Harrow or disk the lime into the soil, and distribute the fertilizer broadcast either prior to seeding or in the row at the time the crop is planted.[14]

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[14] See General Information at end of chapter for experimental results with lime in addition to manure.

**D. Establish a definite liming practice.**[15] Unless the soil is known to be adequately supplied with lime, a definite liming practice should be followed. First determine the lime need of the soil and make an initial application sufficient to assure success with the soil-improving legume of the rotation. If the soil is found to be extremely acid, plan to make two applications of lime before seeding red clover, alfalfa, or sweet clover. Make the first application for the cultivated crop in the rotation, and the second after the land has been plowed for the legume, whether it is to be seeded alone or with a nurse crop. When the lime requirement is found to be less than a ton and a half of limestone or its equivalent to the acre, make only one application and that to the land plowed for the legume. After the lime requirement has been fully satisfied, the future applications, made once every four to five years, should be made for the cultivated crop in the rotation rather than for the small grain in which the clover is seeded. In this way the lime will become thoroughly incorporated with the plowed soil prior to the seeding of the legume.[16]

## GENERAL INFORMATION

### 1. Composition of Liming Materials

**A. Chemistry of lime.** Limestone rock, the source of practically all agricultural lime, contains calcium or both calcium and magnesium in the form of carbonate. The chemical formula for calcium carbonate is $CaCO_3$. When the stone is burned, carbon dioxide gas ($CO_2$) is given off into the atmosphere. This change due to heating may be expressed thus:

$$CaCO_3 - CO_2 = CaO$$

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[15] See Chapter VII for specifications for the use of lime in field-crop rotations.

[16] See General Information at end of chapter for experimental results from systematic liming at Tenn. Exp. Sta.

Burned lime consists of calcium and oxygen. The formula is $CaO$, and the chemical name is calcium oxide. Any magnesium carbonate in the limestone would, on burning, change in a similar manner to magnesium oxide ($MgO$). Calcium has an atomic weight of 40, carbon 12, and oxygen 16. Calcium carbonate then would have a molecular weight of $40 + 12 + (3 \times 16) = 100$. Calcium oxide ($CaO$) would weigh $40 + 16 = 56$. Carbon dioxide ($CO_2$), $12 + (2 \times 16) = 44$. Therefore, 100 pounds of pure calcium limestone—known chemically as calcium carbonate—contains 56 pounds of $CaO$ and 44 pounds of $CO_2$. The carbon dioxide will not reduce soil acidity; therefore, the 56 pounds of burned lime corrects just as much acidity as 100 pounds of limestone. To determine the amount of pure burned lime equivalent to a ton of pure limestone, take $\frac{56}{100}$ of 2000 pounds, which is 1120 pounds. Assuming that pure limestone costs a farmer \$3 a ton delivered, then a ton of burned lime would be worth $\frac{2000}{1120}$ of \$3, or $\frac{100}{56}$ of \$3, which is \$5.36.

When burned lime is exposed to the atmosphere it becomes air-slaked. The change is just the reverse of that which takes place in burning—the burned lime ($CaO$) absorbs carbon dioxide ($CO_2$), forming calcium carbonate ($CaCO_3$). Air-slaked lime, then has the same chemical composition as ground limestone.

Dolomitic limestone contains magnesium carbonate ($MgCO_3$) which has an atomic weight of 84, that is $24 + 12 + (3 \times 16)$. Eighty-four pounds of carbonate will correct the same amount of acidity as 100 pounds of calcium carbonate or 56 pounds of calcium oxide.

When burned lime is treated with water, a chemical change takes place which we ordinarily call *slaking*. This chemical change produces heat. Water ($H_2O$) unites with the burned lime ($CaO$) to form hydrated lime ($Ca(OH)_2$). The change can be expressed as follows: $CaO + H_2O = CaOH_2O$, commonly written $Ca(OH)_2$.

This hydrated lime weighs 74, that is (40 + (2 × 16) + (2 × 1)). The water has no value in correcting acidity; therefore, the 74 pounds of hydrated lime corrects just as much acidity as the 56 pounds of burned lime.

**B. Composition table.** In Table XXIII is given more detailed information relative to the composition of the different forms of lime.

TABLE XXIII

COMPOSITION OF DIFFERENT FORMS OF LIME

| Name of Material | Chemical Form of Lime | Per Cent CaO when Pure | Average Purity Per Cent | Average Amount to Equal 1 Ton CaO |
|---|---|---|---|---|
| Limestone......... | Carbonate | 56.0 | 95 | 3759 |
| Burned lime....... | Oxide | 100.0 | 80 | 2500 |
| Hydrated lime..... | Hydroxide | 75.7 | 90 | 2937 |

**C. Factors for interpreting composition.** The following factors may be used to change one form of lime to an equivalent amount of some other form.

Calcium oxide × 1.79 = calcium carbonate
Calcium oxide × 1.32 = calcium hydroxide
Calcium carbonate × 0.56 = calcium oxide
Calcium carbonate × 0.74 = calcium hydroxide
Calcium hydroxide × 0.76 = calcium oxide
Calcium hydroxide × 1.35 = calcium carbonate
Magnesium oxide × 1.40 = calcium oxide
Magnesium carbonate × 1.19 = calcium carbonate

**D. Gypsum.** Calcium sulfate ($CaSO_4$), often called *gypsum* or *land plaster,* is sometimes considered a form of agricultural lime. It was used very extensively by farmers at one time in the treatment of soils, but with the development of the modern lime and fertilizer industries its use has been replaced by more efficient methods of liming and fertilization. Gypsum is still used in certain sections of the Northwest, particularly for alfalfa, where the beneficial effect is more often due to the sulfur than to the calcium. Gypsum should not be considered a liming material since it will not counteract soil acidity. Any benefit resulting from its use is due, largely at least, to the sulfur, or possibly to the calcium, acting as a nutrient to the crop. If lime and fertilizer are used, both of these elements are furnished in adequate amounts, so that except under special conditions gypsum should not be used.

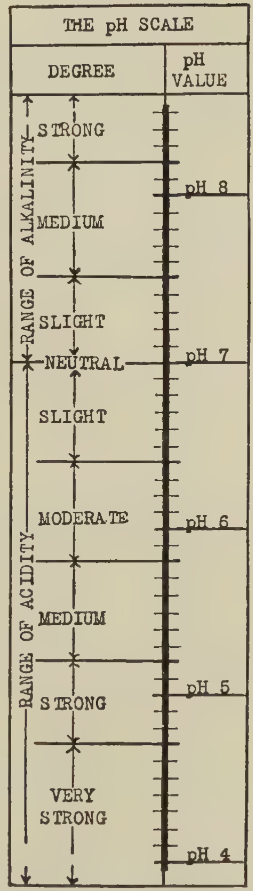
**E. Wood and coal ashes.** Wood ashes are of value in counteracting soil acidity. When unleached, a ton of wood ashes is equivalent to about 1000 pounds of ground limestone or 500 pounds of burned lime. They also contain certain plant-food elements other than calcium and magnesium, and may be of considerable value as a fertilizer. The potash content is particularly high, and, where this element is deficient in the soil, wood ashes may prove a good fertilizer as well as an effective liming material. The beneficial effect of wood ashes is often due largely to the phosphoric acid which they contain. A ton contains as much phosphoric acid as 400 to 500 pounds of the average mixed fertilizer. Coal ashes, on the other hand, are of very little value as either lime or fertilizer. In fact, they are seldom worth the cost of applying to the land. The application of sifted coal ashes to heavy clay soils may improve the physical condition somewhat.

## 2. THE HYDROGEN-ION CONCENTRATION AND THE *p*H SCALE FOR MEASURING SOIL ACIDITY

The degree of soil acidity is very often expressed in terms of the hydrogen-ion concentration of the soil solution.[17] This hydrogen-ion method of measuring acidity necessitates the use of a scale by which soils may be classified according to the intensity of acidity or alkalinity. This so-called *p*H scale is shown in Fig. 135.

[17] See page 51 for discussion of ions and ionization.

The degree of acidity is expressed in terms of $p$H, the intensity of acidity or alkalinity being shown by the $p$H number. A neutral soil, one that is neither acid nor alkaline, is represented by $p$H 7. A smaller $p$H value than 7 indicates acidity, and the smaller the figure the greater the acidity. In the same way, figures larger than 7 represent alkalinity, and the larger the figure the greater the alkalinity. Soils are seldom more acid than $p$H 4.5, or more alkaline than $p$H 8.5. Productive farm soils generally have a $p$H between 5 and 7. While in the $p$H scale the degree of acidity is expressed by the $p$H figure the value of the $p$H unit varies, depending on the intensity of acidity.[18] For example, a soil with a reaction of $p$H 4 is 10 times as acid as one with a reaction of $p$H 5 and 100 times as acid as one with the reaction of $p$H 6. However, the soil does not require lime in the proportions these figures indicate.



*This scale compares pH values with the terms often used in stating the degree of soil acidity or alkalinity.*

FIG. 135. THE $p$H SCALE. (Bul. 190, Nat. Lime Assoc.)

The matter of determining the exact amount of lime to apply to a soil, even on the basis of its hydrogen-ion concentration, is further complicated by certain soil characteristics influencing the effectiveness of lime in changing the $p$H reaction. For example, it requires much more lime to produce a given change in a clay soil than in one sandy in character. Likewise, a soil well supplied with organic matter, or one that is poorly drained, requires more lime to produce a given reaction. Although the *p*H scale may have some advantages over other methods in designating the intensity of acidity, it does not provide a simple and practical unit of measure.

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[18] The acidity intervals vary logarithmically.

In order to make practical use of the *p*H scale in determining the amount of lime to apply, it is necessary to know the approximate amount necessary to produce a given change in the *p*H reaction. Table XXIV gives approximate amounts in pounds of calcium oxide needed to the acre to produce the specified change in *p*H for three distinct classes of soil. At best it should be considered merely as a guide.[19]

TABLE XXIV

POUNDS OF CALCIUM OXIDE REQUIRED TO THE ACRE TO CHANGE *p*H REACTION *

| Class of Soil | From *p*H 6 to *p*H 7 | From *p*H 5.5 to *p*H 7 | From *p*H 5 to *p*H 6 | From *p*H 4.5 to *p*H 6 |
|---|---|---|---|---|
| Sand....... | 425 | 850 | 1275 | 1700 |
| Loam...... | 850 | 1275 | 1700 | 2125 |
| Clay....... | 1275 | 1700 | 2125 | 2550 |

* Bul. 190, Nat. Lime Assoc., Washington, D. C.

Another method of interpreting the *p*H reaction in liming practice is suggested by the National Lime Association. See Table XXV and discussion following. It takes into consideration variation in soil texture and organic-matter content of the soil, but fails to take into account the fact that the *p*H unit varies with the degree of acidity. However, like the preceding table, it may be used as a guide.

Table XXV may be used as follows: If it is desired to change the reaction of a soil from *p*H 5.1 to *p*H 6.5 the difference between these two numbers, or 1.4, multiplied by the amount of oxides required to change the reaction 1 *p*H (as shown in the above table) will be the total amount of oxides that must be applied. Thus, if the soil happens to be a sandy loam with a high content of organic matter, the total amount of the lime oxides required will be 1000 × 1.4 = 1400 pounds lime oxides.

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[19] For use of the *p*H scale in the acidifying of soils for the production of acid-loving crops, see page 466.

In order to determine the amount of liming material required to supply 1400 pounds of lime oxides, divide 1400 by the percentage of total lime oxides contained in the material and multiply by 100.

TABLE XXV

GUIDE FOR DETERMINING THE RATE OF APPLICATION OF LIME *

| Type of Soil | Approximate Pounds of Calcium Oxide Required to Change Reaction 1.0 *p*H (Acre Basis) | | |
|---|---|---|---|
| | Low Organic Matter | Medium Organic Matter | High Organic Matter |
| Clay loams and silt loams | 1500 | 1750 | 2000 |
| Loams ............... | 1000 | 1250 | 1500 |
| Sands and sandy loams. | 500 | 750 | 1000 |

* Bul. 190, Nat. Lime Assoc., Washington, D. C.

Thus, if the material to be used is hydrated lime with a total lime oxide content of 70 per cent, the amount required will be 2000 pounds.

### 3. OTHER METHODS OF DETERMINING THE AMOUNT OF LIME NEEDED

There are several simple methods, other than the litmus-paper test, for determining the lime needs of the soil.[20] The Teskit, the Richorpoor, the Truog, and the Soiltex methods are all practical. In most counties soil-testing service may be secured from the county agricultural agent. When desired, samples may be sent to the state agricultural college for testing. Irrespective of the method used in testing, or by whom the test is made, it is essential that the sample be taken properly.

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[20] See page 254 for litmus-paper test for acidity.

In sampling, dig a hole 7 inches deep. With the spade, carefully straighten a side of this hole, and then shave off several pints of soil, being careful to get approximately the same amount for each inch of depth. In this way, sample the surface of a field in eight or ten different places, each of which appears representative of the field.

To sample the subsoil, dig a hole to a depth of 2 or 3 feet, and in the same manner shave off a representative slice of soil from the bottom 6 inches. A soil auger, if available, should be used instead of a spade for sampling both surface soil and subsoil. In taking a subsoil sample with an auger be careful to remove any surface soil that may adhere to the core of subsoil as it is removed. If vegetative growth indicates little or no acidity, it is well to pour a few drops of dilute hydrochloric acid on the subsoil sample. If the acid bubbles on coming in contact with the soil, excess carbonates are present and further testing is unnecessary.

The surface-soil samples may be numbered and each tested separately if time permits or if a lime-requirement map is to be made. Otherwise, mix these samples thoroughly and take a small representative sample for testing. If the field tested is large or if variation in acidity is indicated by differences in vegetative growth, sample the field in sections, securing a composite sample of surface soil from each section, or test each sample separately and construct a lime-requirement map of the field.

The Teskit and the Soiltex may be used in the field since it is not necessary to dry the soil before testing. For either the Richorpoor or the Truog test the soil should be thoroughly dried.

**A. Teskit test.** This is a simple colorimetric test of the *p*H reaction of the soil. The accurate determination of the *p*H reaction of a soil requires a potentiometer which can be operated only by one trained in laboratory technique. Several colorimetric testing outfits are available with which the approximate *p*H of a soil may be determined. The Teskit is the simplest and probably that best suited to the requirements of farmers or vocational students. It consists of a standard solution, a porcelain block, and a color chart. A small representative sample of soil is placed in one end of the depression in the porcelain block. The solution is added in slight excess of amount to saturate the sample. This excess after passing through the sample is drained to the opposite end of the depression in the block and the color compared with the chart. The solution on coming in contact with the sample is changed in color depending on the degree of acidity of the soil.

The Morgan test is a more elaborate colorimetric method which employs four solutions instead of one. It is operated similarly to the Teskit and gives more reliable results.

**B. Richorpoor test.** A properly prepared potassium thiocyanate solution is needed for this test. Place approximately one inch of the dried soil in a test tube or a small medicine vial. Pour in sufficient Richorpoor solution (potassium thiocyanate) to cover the soil to a depth of 1 inch in addition to saturating it. Place the thumb over the opening and shake vigorously for about one minute. Let the soil settle. Shake again and let stand 15 to 20 minutes. If the solution remains colorless, the soil is not acid. The degree of acidity is shown by the intensity of the red color of the solution. Compare with color chart or with color of solution from soil of known acidity which has been used as a check.

**C. Soiltex test.** Place about one-fourth teaspoonful of soil in a small dish or on a creased piece of wax paper. Saturate with the bluish-green Soiltex solution, by adding slowly, drop by drop, to one edge of the soil. Add several drops in excess of the amount needed for saturation. After the solution has been in contact with the soil for one minute, tip the dish or paper so that the excess solution drains from the opposite side of the soil from that to which it was applied. If the solution coming from the soil is blue to bluish-green, the soil does not require lime. A yellowish-green to yellow color indicates acidity. Compare the color of the solution that has passed through the soil with the color chart of the Soiltex test.

**D. Truog test.** Place exactly 10 grams of the dried, pulverized soil in a 250-cc. Erlenmeyer flask. Add 5 cc. of calcium chloride-zinc sulfide solution (the reagent furnished by the manufacturers of the Truog test). Add 75 cc. of distilled water, shake, and boil for one minute. Moisten a piece of lead acetate paper with distilled water and place across the mouth of the flask. Continue to boil for exactly two minutes. If the soil is acid, the paper will be darkened. The darker the paper the more acid the soil. Compare color of lead acetate paper with color chart furnished by the manufacturers of the Truog test.

**E. How to make a lime-requirement map.** Draw a rough sketch of the field to be mapped. Divide the field into a number of areas of approximately 1 acre each. Number them. Locate these acre areas in the field and take a sample of surface soil from the approximate center of each. Number the samples to correspond to the number assigned to the respective acre division of the field. Test the samples by means of one of the standard methods, and record the results in terms of limestone requirement on the respective acre areas of the map. The areas with different limestone requirements can now be outlined on the map. Color each area and prepare a legend giving the amount of lime indicated by each color used.

Sample the subsoil in the center of each quarter of the field. Test for carbonates with hydrochloric acid. If carbonates are not present, test the subsoil as you did the surface, and record the degree of acidity on the respective areas of the map.

## 4. How Lime Benefits the Soil

It is not acidity itself that injures crops. The injury is due to the development in acid soil of conditions which may be unfavorable to plant growth. To understand the beneficial effect of lime, it is necessary to know something about the relationship of acidity to certain soil factors which affect the growth of crops.

Aluminum is a constituent of agricultural soils. It normally occurs in relatively large amounts and, when in a soluble form, it may have a toxic or poisonous effect on certain plants. Solubility of aluminum in soils increases as the acidity becomes greater. If lime is applied in adequate amounts, the aluminum is changed to an insoluble form which does not injure even the sensitive crops.[21]

Commercial fertilizers will seldom produce maximum benefit on extremely acid soils. Under such conditions the available phosphoric acid of the fertilizer may combine with iron or aluminum, thereby becoming unavailable. The use of the fertilizer material, sulfate of ammonia, increases acidity; and when applied to acid soils for ordinary crops, additional lime should be used.

Certain soil organisms, particularly the beneficial soil bacteria, do not thrive in a very acid soil. The application of lime makes the soil more favorable for their functioning. At the same time, other organisms, such as fungi, which may injure crops, appear to be less active in soils well supplied with lime. It would seem that the legume bacteria, and possibly the independent nitrogen-gathering organisms of the soil, function more efficiently when an acid soil is limed. The Ohio Experiment Station reports finding nearly twice as many bacteria in the surface soil of a limed plat as in that of an unlimed plat.[22] At the same time, the fungous content was found to be reduced by liming to one-fourth that of the unlimed plat.

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[21] See Chapter I for essentials of chemistry.

[22] Ohio Exp. Sta. Bul. 382.

Lime is essential for the normal decomposition of soil organic matter. When it is applied to a very acid soil, the rate of decomposition may be hastened, and as a result the plant-food in the organic matter is made available more rapidly. Lime also lessens the possibility of poisonous residues' accumulating in the soil as the organic matter decomposes. Properly limed soils seldom become toxic to the common farm crops.

Lime may also be beneficial as plant-food. Calcium and magnesium are both essential elements of growth. The former is always an important constituent; the latter is found in most of the lime used in the treatment of soils. Crops such as alfalfa and clover, which respond so well to lime, are known to need relatively large amounts of calcium as a nutrient.

When applied in large amounts to heavy clay soils, lime improves the physical condition. In practice, lime is seldom applied in sufficient quantities to loosen a clay soil materially. The benefit of lime in this respect has been overrated.

### 5. How Lime May Injure Plants

Overliming may do as great injury as excess soil acidity. While all the factors responsible for such injury are probably not fully understood, one important cause of injury is the effect of excess lime on the availability of certain soil nutrients. Both boron and manganese become less available to plants; likewise, the effectiveness of phosphatic fertilizer materials may be reduced. No doubt other changes of a chemical and biochemical nature unfavorable to the growth of plants may take place in the soil complex as the result of overliming.

### 6. Experimental Results

The value of lime on acid soils has been demonstrated time after time through field tests conducted by farmers, and measured by many carefully conducted experiments on farms of various experiment stations. Brief summaries of several of the well-known lime experiments are given in the following paragraphs.

**A. Pennsylvania results.** Table XXVI gives the results over a forty-year period from burned lime used in addition to manure, in a four-year rotation of corn, oats, wheat, and mixed hay. The lime has been applied at the rate of 2 tons of burned lime to the acre, once in four years for corn, and manure at the rate of 6 tons to the acre has been applied in alternate years for corn and wheat. Although the increased yields have not been sufficient to pay for the cost of the lime treatment, it should be borne in mind that the rate of application has been excessive.

TABLE XXVI

Pennsylvania Results—Lime with Manure

| Treatment | Yields | | | | Value of Increase * |
|---|---|---|---|---|---|
| | Bu. Corn | Bu. Oats | Bu. Wheat | Lbs. Hay | |
| Manure and lime | 63 | 44 | 24 | 4223 | ..... |
| Manure........ | 56 | 42 | 24 | 3804 | ..... |
| Increase....... | 7 | 2 | 0 | 419 | $7.10 |

* Same crop valuations used as for Table XVII.

At the end of the first forty-year period, part of the plats in the old Pennsylvania fertilizer experiment were limed. In discussing the results at the end of an additional eight-year period, Noll, Gardner, and Irvin summarize the results as follows:

> After forty years without lime, there was an increase from liming with every treatment; the greatest was where sulfate of ammonia had been used.

Results of an additional ten-year period have not materially modified these figures.

The effectiveness of limestone compared with hydrated lime on clover and timothy hay over an eighteen-year period has been determined in another experiment in Pennsylvania. In summarizing the results, J. W. White states:

> The average of the three rates of application shows a production of 2412 pounds (hay) for limestone and 2504 pounds for hydrated lime, a difference of 92 pounds in favor of hydrated lime. The vegetation on the unlimed area consisted of weeds and was of no economic value. The relatively small differences (between the limestone and hydrated-lime treatments) may be attributed to soil variations and other unavoidable experimental errors.

**B. Ohio results.** At the Ohio Experiment Station, lime has been applied since 1900 to one-half of each plat of a fertilizer experiment in which a rotation of corn, oats, wheat, clover, and timothy has been grown. During the first five years in which crops were harvested separately from the limed and unlimed halves of the plats, lime increased the yields 21 per cent. The increases in the second, third, and fourth rotations were 23, 55, and 84 per cent, respectively. In discussing these results, C. G. Williams, the late director of the Ohio Experiment Station, wrote:

> Clover has shown the largest relative effect from liming, corn next, and oats least, though there has been some variation in different periods. The general effect has steadily increased from period to period, the average increase produced by liming having amounted to more than four-fifths of the unaided yield of the land during the last five years of the twenty-year period.[23]

In a further discussion of these Ohio results the following summary has been made:

[23] Ohio Exp. Sta. Bul. 381, p. 252.

The average value of the crops less the cost of lime has been $79.16 per acre on plats which received lime but no fertilizer. On the fertilized but unlimed plats the value of the crops less the cost of fertilizer has been $46.57. Stated differently, limestone alone has increased the crops 183 per cent, while fertilizer alone has increased the crops 145 per cent.[24]

In Table XXVII are given the results of another Ohio experiment which deals with the effectiveness of coarse and fine limestone and with hydrated lime.[25] According to the valuations of crops and treatments estimated by the Ohio Experiment Station, the fine limestone applied at the rate of 2 tons to the acre has produced the largest net returns.

TABLE XXVII

OHIO RESULTS WITH LIME

| Treatment | Total Value of Increase | Cost of Liming | Balance |
|---|---|---|---|
| Coarse limestone, 2 tons per acre........ | $13.97 | $ 7.00 | $ 6.97 |
| Coarse limestone, 4 tons per acre........ | 21.61 | 14.00 | 7.61 |
| Fine limestone, 4 tons per acre.......... | 26.09 | 20.00 | 6.09 |
| Fine limestone, 2 tons per acre.......... | 21.06 | 10.00 | 11.06 |
| Hydrated lime, 1½ tons per acre........ | 23.79 | 15.00 | 8.79 |

**C. Tennessee results.** The effect, over an eight-year period, of a 2-ton application of ground limestone is given in Table XXVIII. These results were secured at the West Tennessee Experiment Station at Jackson. In a similar experiment at Knoxville, a ton of burned lime, applied in addition to manure and fertilizer, gave increases in corn, wheat, and hay, over an eight-year period, valued at $27.04.

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[24] Ohio Exp. Sta. Bul. 382.

[25] Ohio Exp. Sta. Bul. 260.

### TABLE XXVIII

#### TENNESSEE LIME RESULTS *

| Crop | Acre Increase | Value of Bu. or Ton of Crop | Value of Increase |
|---|---|---|---|
| 2 crops cowpea hay..... | 0.92 ton | $12.00 | $11.04 |
| 2 crops wheat.......... | 6.10 bu. | 1.00 | 6.10 |
| 2 crops clover hay...... | 2.29 tons | 12.00 | 27.48 |
| 1 crop cotton.......... | 46.10 lbs. seed cotton | ...... | 2.50 |
| 1 crop corn............ | 6.10 bu. | .75 | 4.58 |
| Total value of increase from 2 tons of limestone............. | | | $51.70 |

* Tenn. Exp. Sta. Bul. 119.

Field tests were conducted in eleven different places in Tennessee over a period of five years to determine the relative effectiveness of different forms of phosphorus on limed and unlimed land. The results as recorded in Table XXIX show the effectiveness of lime on corn, wheat, and hay.

### TABLE XXIX

#### TENNESSEE RESULTS SHOWING THE EFFECTIVENESS OF LIME WITH AND WITHOUT SUPERPHOSPHATE

| Treatment | Corn (50 Crops) | Wheat (40 Crops) | Hay (28 Crops) |
|---|---|---|---|
| | Bushels | Bushels | Pounds |
| None........................ | 22.2 | 7.9 | 2307 |
| Lime........................ | 27.3 | 9.8 | 3189 |
| Increase from lime............ | 5.1 | 1.9 | 882 |
| Superphosphate.............. | 28.9 | 17.7 | 3070 |
| Lime and superphosphate...... | 34.6 | 20.4 | 4410 |
| Increase from lime............ | 5.7 | 2.7 | 1340 |

## COMMUNITY STUDIES

1. Visit several clover and alfalfa fields in the community. Test the surface soil with litmus paper in areas of good and poor alfalfa or clover. Is there any difference in the acidity as indicated by litmus?

2. By the use of dilute hydrochloric acid, determine whether or not the subsoil is calcareous.

3. Secure representative samples of surface soil, and of the subsoil also if it is not calcareous. Dry these samples and determine the lime requirement by means of one of the standard acidity tests.

4. Make a lime-requirement map of a 5- to 10-acre field in accord with directions given on page 278.

5. Determine and record the liming practice on several of the better farms of the community. This should include the kind and amount of lime used, the source of lime, the composition, and, for ground limestone, the fineness, the method, the rate of application, and the crop for which applied.

## PROBLEMS

1. If a soil has a limestone requirement of 3000 pounds to the acre of pure calcium limestone ($CaCO_3$), how many pounds of pure burned lime ($CaO$) would be required to neutralize the acidity of the surface soil of an acre? How many pounds of pure hydrated lime ($Ca(OH)_2$)?

2. If pure hydrated lime costs $15 a ton, how much would a ton of pure calcium limestone be worth? A ton of pure burned calcium lime?

3. Determine the cost of 2000 pounds of calcium oxide applied to the land in each of the three forms of lime at the following prices, when it costs 75 cents a ton to apply the material: ground limestone, 95 per cent total carbonates, at $2.50 a ton, $1.50 freight; ground burned lime, 97 per cent calcium oxide, at $10.50 a ton, $2.50 freight; hydrated lime, 92 per cent calcium hydroxide, at $12.50 a ton, $2.75 freight. At these prices, which form should be purchased?

4. On the basis of figures in Table XXIV, how many pounds of 90 per cent pure limestone would be required to the acre to neutralize a loam soil with a reaction of *p*H 5?

5. Using the figures in Table XXV, how many pounds of 90 per cent pure limestone would be required to neutralize a loam soil with a medium organic-matter content and a reaction of *p*H 5?

6. Based on results of the Ohio Experimental Station (Table XXVII), which is the cheaper form of lime: fine limestone at $8.00 a ton, or hydrated lime at $12.00 a ton, when the rate of application is 2 tons of limestone and 1½ tons of hydrated lime?

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# CHAPTER VII

## FERTILIZING

Practically all farmed soils of the eastern half of the United States which have been cropped for as long as ten years will respond to some form of fertilizer. Ultimately, all cropped soils will require fertilization. The elements most often needed are nitrogen, phosphorus, and potassium. Commercial fertilizers, used to supplement the soil supply of plant-food, contain one or more of these elements. Their composition is commonly expressed in terms of nitrogen, phosphoric acid, and potash. Various kinds of commercial chemicals and by-product materials, containing one or more of the three plant-foods, are used in the manufacture of mixed fertilizers. The materials used, such as nitrate of soda, superphosphate, and muriate of potash, are known as *fertilizer constituents, ingredients, chemicals,* or *carriers of plant-food.* A knowledge of their main characteristics and of their composition is of value in the development of an efficient fertilizer practice for the farm.[1]

FIG. 136. THE BENEFIT OF FERTILIZER ON HAY:

Practically all farmed soils of the eastern half of the United States which have been cropped for as long as ten years will respond to some form of fertilizer. Ultimately, all cropped soils will require fertilization.

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[1] See General Information at end of chapter for discussion of fertilizer materials.

A *mixed fertilizer* is one containing two or more fertilizer ingredients. If it contains the three plant-foods—nitrogen, phosphoric acid, and potash—it is termed a *complete fertilizer.* If it contains only two of the constituents, it is called an *incomplete fertilizer.*

Superphosphate invariably is an important ingredient of factory-mixed fertilizers. It constitutes from 1000 to 1500 pounds of each ton of most mixtures of standard concentration. The larger manufacturers have their own acidulating plants in which they produce the superphosphate.[2] The other fertilizer materials are purchased by most manufacturers and mixed with the superphosphate to produce mixtures of the desired composition. In the manufacture of mixed fertilizers,

FIG. 137. A FARMERS' COOPERATIVE FERTILIZER FACTORY (Cooperative G. L. F. Exch.)

Manufacturers in general use care in the selection of constituents, making certain that the plant-food is in an available form and suited to the crop to be fertilized.

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[2] See General Information at end of chapter for explanation of the manufacture of superphosphate.

precaution is taken to incorporate an amount of some material possessing sufficient drying properties to prevent lumping, so that the fertilizer can be applied to the soil by means of fertilizer drills. Such a material is called a *dryer* or *conditioner.* Manufacturers in general use care in the selection of constituents, making certain that the plant-food is in a form available to plants and suited to the crops to be fertilized. By varying the amounts of the materials they are able to produce a mixture of any desired composition, within certain limits of concentration. Sand or other inert material may be incorporated in small amounts to produce the desired concentration. Such material is called *filler.*

**Operations:**

1. Planning the fertilizer practice.
2. Determining when to use superphosphate and potash.
3. Selecting mixed fertilizers.
4. Applying mixed fertilizers.
5. Home-mixing fertilizers.

### 1. PLANNING THE FERTILIZER PRACTICE

In the development of a sound fertilizer program for any system of farming, it must be appreciated that there can be no best composition of fertilizer for any one crop on all soils, nor for all crops on any one soil.

Fertilizers should be used to supplement the soil supply of plant-food, the manure available, and the nitrogen collected by the growth of legumes in the crop rotation. For this reason superphosphate is of primary importance as a fertilizer for most field crops on most soils, whereas nitrogen and potash need be applied in the form of fertilizer only for certain crops and soils. It is apparent, then, that there can be no such thing as a "balanced ration" for crops or a "balanced fertilizer" for soils.

Although the character of both the soil and the crop should be considered in determining a fertilizer program, the rotation, the manure supply, the residual effect of fertilizer treatments, the cost of fertilizer, the price of crops, the expenditure to be made for fertilizer, the value of the land, and the system of land tenure are all of such importance that they deserve careful consideration.

*Soils.* Although, as previously explained, the chemical elements required by plants are present in all soils, the amount of one or more present in a form which the plant can use may be insufficient for satisfactory growth. It is the available plant-food in the soil that determines the fertilizer needs. For this reason a chemical analysis that shows the total amount of nutrients present is of little practical value as a guide in the selection of a fertilizer. Recently developed methods of testing soils for available nutrients have very definite limitations in determining the fertilizer needs, especially of soils used for the production of field crops.

*Crops.* Although crops vary in chemical composition, the selection of a fertilizer should not be based on crop requirements alone. In general, plants contain less phosphoric acid than either nitrogen or potash, and in their economic fertilization more phosphoric acid than either nitrogen or potash is ordinarily required. The value of crops and the intensity with which they are produced are of greater importance than their chemical composition in the selection of a fertilizer.

Since the legumes, such as alfalfa and clover, are capable of utilizing atmospheric nitrogen, little or no nitrogen need be applied in their fertilization. Corn requires a large amount of nitrogen, but for the profitable production of grain and silage, much of this nitrogen must be supplied from other sources than fertilizers. The root and tuber crops have a high potash requirement based on composition, but in their fertilization phosphoric acid should be applied in as large or larger amounts than potash. Fruit crops, though not abnormally high in nitrogen, are often found to require only nitrogen as a fertilizer. The chemical composition of the crop is, after all, of minor importance in determining the kind and amount of fertilizer which it should receive.

*Rotations.* The common practice of basing fertilizer recommendations on the individual field crop and ignoring the rotation is unsound and results in an inefficient system of fertilization. A crop following sod, especially a legume sod, should be fertilized differently from one following a cultivated crop. In selecting a fertilizer for small grain, the composition and the amount which should be used will depend on whether a hay seeding is made with the small grain, and, if so, on the character of the seeding. The individual crops affect differently those crops which follow, and this fact must be considered in selecting a fertilizer.

*Manure.* The application of manure normally justifies a change in the composition and often the amount of fertilizer to be used. Since manure is high in nitrogen and potash and low in phosphoric acid, where it has been applied to the land less nitrogen and potash are needed in the fertilizer. Either superphosphate alone or a fertilizer high in phosphoric acid should be used for a manured crop.

*Residual effect from previous fertilizer treatments.* Fertilizers have a marked residual effect over a period of several years. In a rotation the beneficial effect on crops following the one receiving the fertilizer is due to the residual effect of the phosphoric acid or the potash and not of the nitrogen, for any nitrogen in the fertilizer that is not used by the crop fertilized will largely have leached away before the next season. There is virtually no loss of phosphoric acid by leaching and little loss of potash except in sandy or gravelly soils. It is for this reason that heavy applications of superphosphate, or potash salt, may be made at long intervals except on soils with a high-fixing capacity for either phosphorus or potash or both. If a high-value crop, such as potatoes, enters into a field-crop rotation, enough fertilizer for the whole rotation may often be applied advantageously to this one crop.

Fertilizer materials differ in their residual effect on soil acidity. Most mixed fertilizers increase acidity, though there are now on the market mixtures which have a neutral residual effect. Failure to consider the residual effect of previous applications of fertilizer or manure invariably results in the unwise selection of fertilizers.

*Relative cost of constituents.* The proportion of the different plant nutrients to use, as well as the amounts of each, depends on their relative cost. If phosphoric acid is purchased as superphosphate, a more liberal amount may be used than when bought as part of a mixed fertilizer. The purchase of a concentrated mixed fertilizer, instead of one of low analysis, may effect a saving of as much as 20 per cent. The use of potash may often be justified if purchased as muriate of potash, whereas the higher cost of the potash in a 0-12-5 mixed fertilizer would make its use unwarranted.

*Price of crops.* In periods of either high or rising crop prices, a more expensive system of fertilization may be justified than in periods of either low or falling crop prices. This applies not only to the amount of fertilizer to be used but to the proportion of plant-food as well.

*Expenditure for fertilizer and rate of application.* One of the most important considerations in the selection of a fertilizer, and the one most often overlooked, is the amount of money to be spent to the acre for fertilizer. If only a few dollars can be spent, the fertilizer, for most soils and crops, should consist largely of superphosphate, but as the expenditure for fertilizer increases a larger proportion of it may be spent for nitrogen and potash. Where a mixed fertilizer is being used, the ratio should in general be narrowed as the rate of application is increased.[3] The kind and the composition of the fertilizer, then, should be modified with the rate of application of plant nutrients, or more accurately stated, with the amount to be spent for the fertilizer.

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[3] See page 304 for definition of *fertilizer ratio.*

*Value of land.* The more valuable the land farmed, other things being equal, the greater is the amount justified for its fertilization. The fertilizer treatment to be used on $25- to $75-an-acre land of the general farmer must of necessity cost less than that applied to $300-an-acre land of the vegetable grower. Likewise, if crops are produced under glass, the value of land and equipment is so great that very liberal and costly fertilization can usually be justified.

*Tenure of land.* A tenant system of farming without security of tenure or compensation for unused fertility is never conducive to soil improvement, or, in fact, to an economically sound fertilizer practice. The tenant of necessity selects fertilizer for its immediate effect and plans to apply it in such a manner as to obtain, so far as possible, the full effect on the crop fertilized without regard to its ultimate effect on the soil. Very little progress has been made in this country in developing leasing contracts that make possible the efficient use of fertilizers in tenant farming. Until a radical change is made, tenant farming will continue to result not only in uneconomical production but in soil depletion as well. An owner with a reasonable assurance that the land will be farmed by himself or his family during the future is justified in establishing a long-time fertilizer practice which will maintain or increase the fertility of the soil.

## 2. Determining When to Use Superphosphate and Potash

In establishing an economical system of fertilization, one of the first things to determine is the extent to which superphosphate, or other phosphatic fertilizer material, will satisfy the needs for good crop yields. Where low-value crops, including grain, hay, and silage, are produced, as well as in the fertilization of permanent pastures, the expenditure for mixed fertilizers may be largely if not entirely avoided. By adjusting the rotation to include a legume every three to five years and providing for the efficient utilization of the farm manure, considerable saving may be made by using fertilizer materials such as superphosphate.[4]

**Procedure:**

A. Use superphosphate, rock phosphate, or basic slag.
B. Apply superphosphate with a fertilizer drill or with a lime distributor.
C. Prevent the lumping of superphosphate.
D. Use potash when needed.

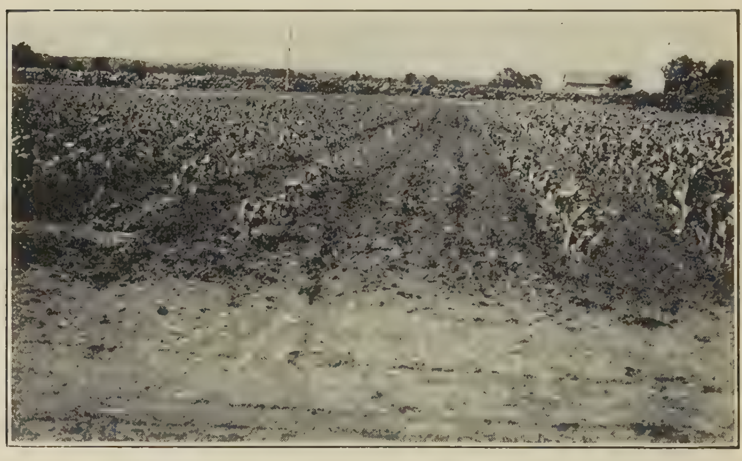

FIG. 138. BENEFICIAL EFFECT OF SUPERPHOSPHATE ON CORN AT THE RHODE ISLAND EXPERIMENT STATION. LEFT: NO TREATMENT. RIGHT: SUPERPHOSPHATE.

In establishing an economical system of fertilization one of the first things to determine is the extent to which superphosphate, or other phosphatic fertilizer material, will satisfy the needs for good crop yields.

**A. Use superphosphate, rock phosphate, or basic slag.** Superphosphate, sometimes called *acid phosphate*, or *acid rock*, even though manufactured by treating rock phosphate with sulfuric acid, does not, when applied to well-drained soils,

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[4] See Chapter VIII for information on leguming land and Chapter IX for information on fertilizing field-crop rotations.

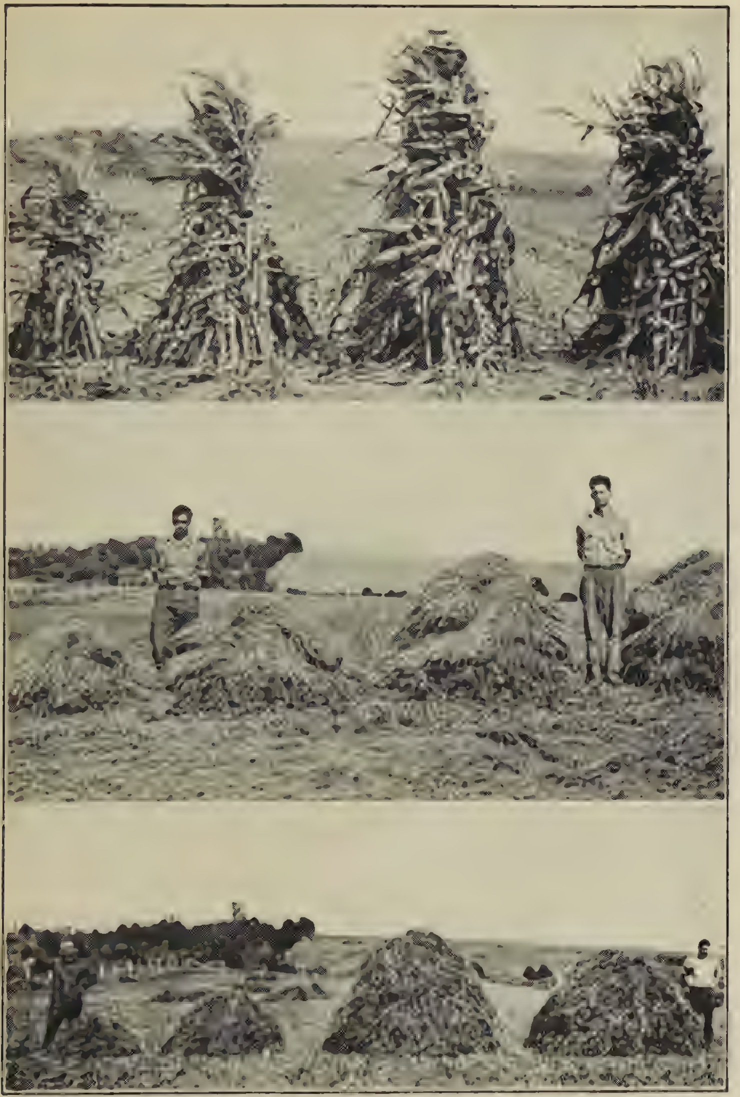

FIG. 139. BENEFITS FROM SUPERPHOSPHATE IN A THREE-YEAR ROTATION OF CORN, OATS, AND CLOVER.

Fertilizer Treatment. Left to Right: None. Manure. Manure, Lime and Superphosphate. Lime and Superphosphate.

By adjusting the rotation to include a legume every three to five years, and providing for the efficient utilization of the farm manure, considerable saving may be made by using superphosphate.

increase the need for lime. In fact, where superphosphate is used, less rather than more lime is needed for alfalfa and clover. Basic slag materially reduces soil acidity.[5] Rock phosphate and bone meal, while having little effect on acidity, lessen rather than increase the amount of lime needed for legumes.

The effective use of superphosphate makes it necessary that the nitrogen needs of the crops be furnished through the growing of legumes or the return of farm manure. At the same time the potash requirements must be supplied through the conservation of the liquid manure and the return of organic matter to the soil. On well-managed livestock farms these requirements are largely met, with the result that expensive mixed fertilizers can be replaced by superphosphate or one of the other phosphatic materials.

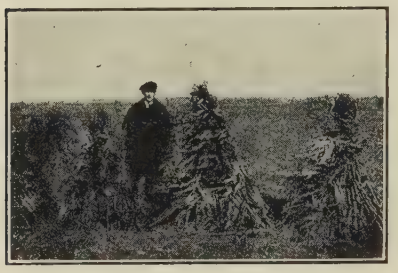

FIG. 140. RESULTS OF A FERTILIZER ON CORN. LEFT TO RIGHT: NO TREATMENT. NITROGEN AND POTASH. SUPERPHOSPHATE. ROCK PHOSPHATE.

Where conditions are made favorable superphosphate, or some other one of the phosphatic materials, when used for grain and hay crops, will give greater returns than an equal investment in mixed fertilizers.

Where legumes fail in the rotation, and manure is not applied, superphosphate alone will not be permanently beneficial. It may give good results for a few years without legumes or manure; but, even on rich soils, provision must be made to replenish the nitrogen and organic-matter supply or else superphosphate will prove inadequate as a fertilizer. Where conditions are made favorable, use superphosphate or some other one of the phosphatic materials for grain and hay crops, as greater returns will be secured from it than from an equal investment in mixed fertilizers. When properly used, rock phosphate gives excellent results.

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[5] See Table XXXI for information on the effect of fertilizing materials on soil acidity.

Of most importance is the fineness of grinding. Rock phosphate should be ground so fine that practically all of it will pass through a 100-mesh sieve. Only when finely ground does the phosphorus, even under favorable soil conditions, become available to crops at a rate sufficiently rapid to be satisfactory. The rate of application should be 600 to 1000 pounds to the acre. Broadcast and plow into the soil with a green-manure crop, or apply with farm manure. When used in this way, rock phosphate will give good results with grain and hay crops. A single application of 600 to 1000 pounds to the acre will suffice for a three-year to a five-year rotation. It gives better results on low- than on high-lime soils, and its effectiveness appears to be reduced when lime is applied.

FIG. 141. A GOOD YIELD OF GRAIN AS A RESULT OF ROCK PHOSPHATE. (Frank I. Mann, Gillman, Ill.)

When properly used, rock phosphate gives good results with grain and hay crops.

**B. Apply superphosphate with a fertilizer drill or with a lime distributor.** Superphosphate should be applied with a fertilizer drill or by means of the fertilizer attachment on the grain drill or planter. When applied in connection with seeding a crop, the rate of application should not exceed 300 pounds to the acre unless provision is made to prevent it from coming in contact with the seed.[6] The better way is to apply the superphosphate with a lime sower as a separate operation. This should be done after the field is plowed, so that it will be thoroughly mixed with the soil during the preparation of the seed-bed. Heavy applications can be made in this way with perfect safety.

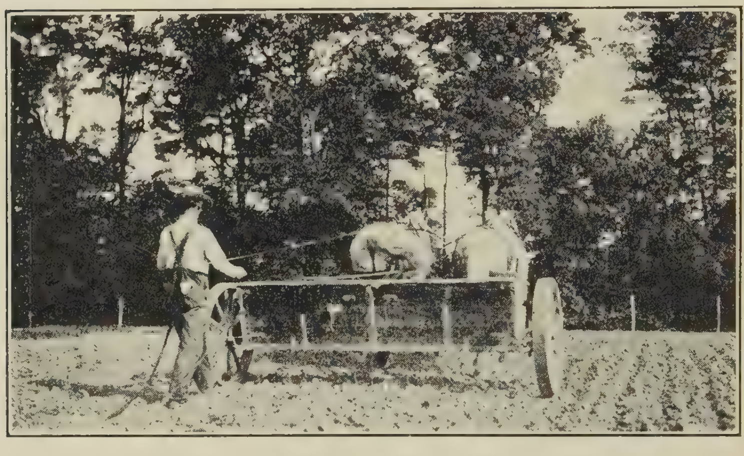

FIG. 142. APPLYING SUPERPHOSPHATE WITH A LIME DISTRIBUTOR.

The better way is to apply the superphosphate as a separate operation with a lime sower.

The rate of application of superphosphate should be equivalent to at least 100 and preferably 150 pounds for each crop of the rotation. Even a larger amount may be advisable for the first several rotations, particularly where phosphorus has not been applied regularly in past years. The application need not be made each year. Instead of 150 pounds annually, 300 pounds may be applied every two years, or 450 pounds every three years. Even though the phosphoric acid in superphosphate is largely soluble in water, it does not leach out of the soil. That not used by the first crop treated will be held by the soil for the use of future crops. The livestock farmer should apply superphosphate or rock phosphate in conjunction with farm manure, as explained in Chapter V.

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[6] Rate of application of superphosphate refers to the 20 per cent grade. If a more concentrated grade such as the 32 or the 45 per cent grade is used, reduce proportionately the rate of application.

**C. Prevent the lumping of superphosphate.** If superphosphate is applied with either the fertilizer drill or the lime distributor, it is essential that it be in good mechanical condition. Lumpy material cannot be distributed satisfactorily. Where it is used with manure, lumping need give little concern, since the lumps break down upon coming in contact with the moist manure. Superphosphate purchased during the early part of the spring fertilizer season is, as a rule, more thoroughly cured than that obtained in late shipments. When superphosphate is properly made and thoroughly cured before it is bagged, it will remain in good condition for drilling if properly stored. When the bagged superphosphate is held for several weeks or more, make provision for proper storing. It should never be stored on a dirt or concrete floor. Unless a dry, board floor is available, boards or straw should be placed under the bags. The bags should never be piled to any great height, as the weight on the lower sacks in the pile may be sufficient to cause caking. Where floor space will permit, set the bags on end instead of piling, even in a low pile. An occasional shifting of the sacks will still further lessen the tendency of the material to lump.[7] The granular form of superphosphate is less subject to lumping than the powdered, and the phosphoric acid in it is as effective.

**D. Use potash when needed.** Some soils are as deficient in potassium as in phosphorus. Those of a sandy or gravelly character, as well as peats and muck, are more often in need of potash than are the heavier loams and clays. Even where soils are naturally well supplied with potash, provision must be made to replenish the supply or else they, too, will ultimately develop a potash deficiency.

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[7] See page 337 for information on storing mixed fertilizers.

In livestock farming most of the crops grown are fed to livestock and frequently additional feed is purchased. Since much of the potash in the feed is regained in the manure, this type of farming largely or entirely replenishes the potash supply of the soil, and the purchase of fertilizer potash thus becomes unnecessary. However, where grain, hay, or other crops are mostly sold from the farm, it soon becomes necessary to apply potash in addition to phosphorus.

When potash is needed, apply muriate of potash at the rate of 100 to 200 pounds to the acre at 3- to 5-year intervals. Obviously, a mixed fertilizer such as the 0–20–20 may be used instead of superphosphate and muriate of potash. If substituted, it should be applied at the same rate as specified for the 20 per cent grade of superphosphate. Unless legume crops are grown successfully and frequently in the rotation, inadequate nitrogen will be supplied, and its purchase as fertilizer will become necessary. The profitable production of the low-value field crops without serious soil depletion necessitates the growing of legume crops, and the efficient use of the farm-manure supply. Although some mixed fertilizer may be used to advantage, the plant-food needs of the crops must largely be supplied more economically. Where cotton, tobacco, vegetables, and other higher-value crops are grown, the plant-food may more often be supplied as mixed fertilizers.

### 3. Selecting Mixed Fertilizers

In selecting a mixed fertilizer, both composition and price should be considered. This necessitates an understanding of the method used in expressing the composition, and of other essentials to the correct interpretation of prices of mixed fertilizers. Also, one should make certain that the fertilizer is suited to both soil and crop.

**Procedure:**

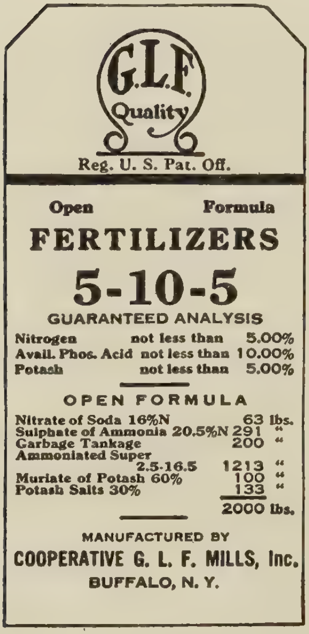
A. Consider factors that are essential in evaluating fertilizers.
B. Evaluate prices.
C. Choose, taking into consideration recommended practice.

**A. Consider factors that are essential in evaluating fertilizers.** The factors to be considered are as follows:

(1) Formula.
(2) Guaranteed analysis.
(3) High analysis *vs.* low analysis.
(4) Possible value of minor fertilizer elements.
(5) Effect on soil acidity.
(6) Unit valuation.

(1) *Formula.* The kinds and amounts of the various materials used in the manufacture of a given mixed fertilizer constitute what is known as the *formula.* It is virtually the recipe followed in mixing a fertilizer. In the same way that definite amounts of flour, sugar, baking powder, and other constituents are used in making a cake, a certain number of pounds of tankage, nitrate of soda, superphosphate, and muriate of potash, or of other fertilizer materials, are used in compounding a ton of mixed fertilizer of a given composition. Whether the fertilizer is mixed by machinery in the fertilizer factory or by hand labor on the barn floor, the amounts and kinds of materials used constitute the formula.

It is not customary for manufacturers to furnish definite information about the formulas of the different grades of fertilizer. Only in exceptional cases do fertilizer laws require that information as to the sources of the different plant-foods be given. A persistent demand by farmers has resulted in the furnishing of such information by certain coöperative organizations. Where this is done the fertilizer is spoken of as having an *open* or a *public formula.*



G.L.F. Quality

Reg. U. S. Pat. Off.

**Open Formula**

**FERTILIZERS**

**5-10-5**

**GUARANTEED ANALYSIS**

| | | |
|---|---|---|
| Nitrogen | not less than | 5.00% |
| Avail. Phos. Acid | not less than | 10.00% |
| Potash | not less than | 5.00% |

**OPEN FORMULA**

| | |
|---|---|
| Nitrate of Soda 16%N | 63 lbs. |
| Sulphate of Ammonia 20.5%N | 291 " |
| Garbage Tankage | 200 " |
| Ammoniated Super 2.5-16.5 | 1213 " |
| Muriate of Potash 60% | 100 " |
| Potash Salts 30% | 133 " |
| | 2000 lbs. |

MANUFACTURED BY

**COOPERATIVE G. L. F. MILLS, Inc.**

BUFFALO, N. Y.

FIG. 143. PUBLIC-FORMULA FERTILIZER. (Coöperative G. L. F. Exch.)

A persistent demand by farmers for information as to the kind and amounts of materials used in mixed fertilizers, has resulted in the furnishing of such information by certain coöperative organizations. Where this is done the fertilizer is spoken of as having an *open* or *public formula.*

Extravagant claims are often made for a particular grade of fertilizer on the ground that it has a fish, bone, or animal base. Great emphasis is sometimes placed on the scientific compounding of factory-mixed fertilizers, and the argument is advanced that they feed the crop throughout the season. Farmers themselves often make the mistake of basing their valuation of a fertilizer on smell and color, rather than on composition. In purchasing mixed fertilizer, do not attach any importance to the odor and color of the fertilizer or to indefinite statements as to the formula. Insist on specific information as to the amounts of the various ingredients of which the fertilizer is composed. Avoid the purchase of mixtures that contain large amounts of low-grade ammoniates, such as garbage tankage, cocoa shells, ground leather, and wool waste, unless the nitrogen furnished by such materials is in excess of that in the guaranteed analysis. Choose an open- or public-formula fertilizer which is properly compounded for the conditions under which it is to be used.[8]

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[8] See Chapters IX to XII for fertilizing different crops.

(2) *Guaranteed analysis.* The chemical composition of commercial fertilizers is guaranteed by the manufacturer. Most states have fertilizer laws which require the manufacturer to print, either on the bag or on a tag attached thereto, a statement furnishing certain information as to the plant-food content of the fertilizer. Such a statement is known as the *guaranteed analysis,* and, when correctly interpreted, furnishes valuable information about the composition and value of the fertilizer.

The more progressive fertilizer manufacturers have within recent years simplified the guaranteed analysis, and only occasionally is a complicated guarantee such as the following used:

### Guaranteed Analysis of Complete Fertilizer

| | Per Cent |
|---|---|
| Nitrogen | 2.00 to 2.50 |
| Ammonia (or equivalent to ammonia) | 2.43 to 3.04 |
| Soluble phosphoric acid | 2.00 to 8.00 |
| Reverted phosphoric acid (citrate soluble or precipitated) | 2.00 to 4.00 |
| Available phosphoric acid | 8.00 to 12.00 |
| Insoluble phosphoric acid | 1.00 to 2.00 |
| Total phosphoric acid | 9.00 to 14.00 |
| Equivalent to tricalcium phosphate (or bone phosphate) | 19.65 to 30.56 |
| Potash (sometimes total) | 2.00 to 3.00 |
| Equivalent to sulfate of potash | 3.70 to 5.55 |
| Total plant-food | 51.78 to 84.65 |

In interpreting this analysis, take into consideration only the first column of figures. Most state fertilizer laws make no restriction as to the accuracy of the figures in the second column. This fertilizer is guaranteed to contain 2 per cent nitrogen, which is equivalent to 2.43 per cent ammonia. The phosphoric-acid content is expressed in several different ways. The farmer is primarily interested in the amount of available phosphoric acid, which in this case is 8 per cent. The term *equivalent to tricalcium phosphate* is very misleading, since it expresses the phosphoric-acid content in terms of a chemical compound occurring in very small amounts if at all. Similarly, the term *equivalent to sulfate of potash* does not guarantee the potash to be in the sulfate form, but merely means that, if the 2 per cent of potash were in the form of sulfate of potash, the fertilizer would contain 3.70 per cent of the salt.

The following simplified guarantee would furnish all the information needed relative to the composition of this fertilizer.

| | Per Cent |
|---|---|
| Nitrogen | 2 |
| Available phosphoric acid | 8 |
| Potash | 2 |

If one understands the interpretation of a complicated guaranteed analysis, it is not difficult to interpret the simpler type which is more common today. Keep in mind the fact that, from the standpoint of analysis, the value of the fertilizer depends on the amounts of nitrogen, phosphoric acid, and potash which it contains. Study the guaranteed analysis until the composition of the fertilizer in terms of the three plant-food constituents is understood.

(3) *High analysis vs. low analysis.* The chemical composition of the fertilizer is often expressed by a series of three figures, such as 5–10–5. These figures express the percentage of nitrogen, available phosphoric acid, and soluble potash, respectively, and constitute the *analysis.*

The term *fertilizer ratio* refers to the proportion of the nitrogen, phosphoric acid, and potash present, irrespective of the concentration. A 5–10–5 analysis would contain 2 parts of phosphoric acid to 1 part each of nitrogen and potash, or the ratio of nitrogen, phosphoric acid, and potash would be 1–2–1. Other analyses having this same ratio are 4–8–4, 8–16–8, and 10–20–10.

A *wide ratio* is one in which a constituent occurs in relatively large amounts as compared with the others; a *narrow* *ratio* is one in which the constituents occur in approximately the same amounts. A 1–4–1 would be considered a wide ratio, and a 2–3–2 would be considered a narrow one.

The terms *high analysis* and *low analysis* are applied to fertilizers on the basis of their concentration. A fertilizer is of high analysis when the figures of the analysis total 20 or more. If they total less than 20 the fertilizer is of low analysis. The 5–10–5, with a total of 20 per cent of nitrogen, phosphoric acid, and potash, would class as a high-analysis fertilizer; while the 4–8–4 would be of low analysis, since it contains only 16 per cent of plant-food.

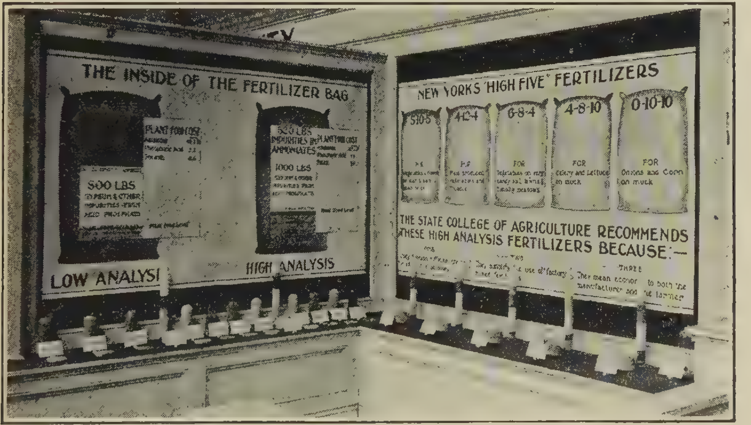
THE INSIDE OF THE FERTILIZER BAG
500 LBS
1000 LBS
LOW ANALYSI
HIGH ANALYSIS
NEW YORKS 'HIGH FIVE' FERTILIZERS
6-8-4
4-8-10
0-10-10
FOR
FOR
FOR
THE STATE COLLEGE OF AGRICULTURE RECOMMENDS THESE HIGH ANALYSIS FERTILIZERS BECAUSE:—

FIG. 144. USE HIGH-ANALYSIS FERTILIZER.

Where factory-mixed fertilizers are used, those of high analysis are relatively cheaper than those of low analysis.

Where factory-mixed fertilizers are used, those of high analysis are relatively cheaper than those of low analysis. The reason for this is that there are certain overhead manufacturing charges which are relatively constant per ton of fertilizer, irrespective of its composition. For example, the cost of mixing, of bags and bagging, and of freight is the same for a high- as for a low-analysis fertilizer. The additional plant-food secured through purchasing a mixed fertilizer of high composition is always secured at a relatively low cost, often lower, in fact, than a farmer must pay for the same plant-food in fertilizing materials such as nitrate of soda, superphosphate, and muriate of potash. As a specific example, compare in price the 4–8–4 with the 6–12–6. The latter contains the same ratio of plant-food constituents, but is 50 per cent more concentrated. Consequently, it would require 3000 pounds of the 4–8–4 to furnish the same amount of plant-food as 2000 pounds of the 6–12–6. At current prices, the 4–8–4 costs about $30 a ton. The 6–12–6 can be purchased for approximately $40 a ton. For the additional $10 paid for the 6–12–6, one secures the equivalent of one-half ton of a 4–8–4. In other words, this additional plant-food costs at the rate of $20 a ton of 4–8–4. By substituting 1 ton of 6–12–6 for 1½ tons of 4–8–4 there is a direct saving of $5, which is equivalent to more than 10 per cent. Not only is the high-analysis fertilizer cheaper, but at the same time it will average a better quality since in its manufacture there is not the opportunity for using much low-grade material such as garbage tankage and leather scrap.

Mixed fertilizers containing as much as 25 per cent or more of plant-food are called *concentrated* or sometimes *double-strength fertilizers*. Their manufacture has been made possible by the use of the more concentrated fertilizer materials such as ammo-phos, urea, and double- or treble-superphosphate. There is no greater danger of injuring the germination of the seed or of burning the crop with these concentrated fertilizers than with those of normal strength provided the rate of application is reduced so that plant-food is supplied in the same amounts. They have been found in most instances to be as effective as the less-concentrated mixtures, and generally sell for less per unit of plant-food. They do not normally contain so large a proportion of the minor fertilizer elements as do less-concentrated mixtures. An objection frequently raised to their use is that difficulty is encountered with many fertilizer distributors in reducing adequately the rate of application.

There are still some products on the market containing little plant-food, but claimed to be of great value in increasing crop yields. They are often pictured as "nature's plant-food," or "odorless fertilizers," and the claim is made that in some miraculous way they stimulate or vitalize crop growth. Such materials are well deserving of the name *patent-medicine fertilizers.* While they may be of some value in stimulating the growth of plants, they always sell at a prohibitive price, and have no place in the economic fertilization of farm crops.

In purchasing factory-mixed fertilizers, consider only those of high analysis, including the concentrated mixtures. Low-analysis mixed fertilizers are always relatively expensive; and patent-medicine fertilizers are exorbitant in price from the standpoint of their plant-food content. In purchasing without information as to the formula, relatively better-quality materials will be secured in high-analysis than in low-analysis mixtures. An analysis with at least 30 per cent of plant-food generally should be selected, and if prices justify, a concentration of 40 to 50 per cent should be purchased. The price as well as the composition should always be taken into consideration in choosing mixed fertilizers.[9]

The need for mixed fertilizers in any given state can be supplied by ten or twelve analyses; and, for the country at large, twenty different analyses should satisfy all practical needs. Even though there has been a concerted effort made by agricultural workers and fertilizer manufacturers to reduce the number of grades, and some real progress has been achieved in this direction, there are still far too many different grades or analyses on the market. A further drastic reduction in the number of analyses would greatly simplify the selection by farmers and materially reduce manufacturing overhead for producers.

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[9] See page 310 for method of comparing prices of high-analysis fertilizers.

(4) *Possible value of minor fertilizer elements.* All mixed fertilizers contain plant nutrients other than nitrogen, phosphoric acid, and potash. They are generally considered of little or no practical fertilizing value. Their presence is not indicated by the guaranteed analysis. The fertilizer-control laws of most states ignore them entirely. While some of these minor fertilizer elements are normally supplied by the natural fertilizer materials, others may be added by the manufacturer.[10]

An additional fertilizing value is often claimed because of the presence of plant-food other than nitrogen, phosphoric acid, and potash. A fertilizer may be said to contain rarer elements or plant-food in excess of that in the guaranteed analysis. In considering the value of such claims, it is well to remember that outside of very sandy soils, certain mucks and peats, and a few other abnormal soils, the rarer elements, which do not commonly occur in mixed fertilizers of normal concentration, have not been found beneficial so long as the soil is efficiently managed. Until fertilizer laws in most states are revised, a purchaser has no assurance except the statement of the manufacturer as to the presence of nutrients other than nitrogen, phosphoric acid, and potash.

(5) *Effect on soil acidity.* Most mixed fertilizers increase soil acidity. This acidifying effect is due most often to such materials as sulfate of ammonia, and not, as so commonly believed, to superphosphate. Other fertilizer materials besides sulfate of ammonia have an acid residual effect on the soil. Some reduce acidity, but most of them have no material effect on it.[11]

By selecting the proper fertilizer materials, and when necessary, by using some lime in the mixture, fertilizers can be produced which have an acid effect, others that have an alkaline, and still others that have a neutral effect on the soil. Likewise in home-mixing fertilizers the desired effect on soil acidity may be secured.[12]

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[10] See Chapter I for information on essential and minor nutritive elements.

[11] See Table XXXI for information on the effect of fertilizer materials on soil acidity.

For crops requiring a very acid soil, or for soils with an alkaline reaction, select an acidifying fertilizer. Such a fertilizer should also be chosen where potato scab is troublesome. In the fertilization of crops which are very sensitive to acidity, such as beets, cauliflower, and onions, use a mixture which has a neutral or a slightly alkaline residual effect. Where mixed fertilizer is used in a grain- and hay-crop rotation, and where the cost is no greater, use one having an alkaline effect since it will reduce somewhat the amount of lime required for the legume crop in the rotation.

(6) *Unit valuation.* In the purchase of mixed fertilizers and of fertilizer materials for home-mixing, an understanding of the method of evaluating fertilizers on the unit basis is desirable, if not absolutely essential. The term *unit* is commonly used by manufacturers to express the composition of fertilizer materials, and *unit valuation* to designate the price. A unit means 1 per cent of a ton, or 20 pounds. Unit valuation is the value of a unit, or 20 pounds, of a given plant-food. Obviously, the units of a given plant-food in a fertilizer would be identical with the percentage of the same plant-food. Nitrate of soda, for example, analyzing 16 per cent nitrogen contains 16 units of nitrogen to the ton. If this nitrate of soda costs $40 a ton, each of the 16 units of nitrogen would cost $2.50, which is the unit valuation.

Unit valuation is used in determining the prices of factory-mixed fertilizers. When the unit valuation of each of the three constituents of plant-food is known, one can readily determine the cost of the constituents necessary for a ton of any analysis of complete fertilizer. For example, assume the following unit valuations: nitrogen $2.50, phosphoric acid $1, and potash 90 cents. The cost of the constituents for a ton of 5–10–5 fertilizer can be determined as follows:

---

[12] See page 337 for acid and non-acidifying formulas to be used in home-mixing.

5 × $2.50 = $12.50 cost of nitrogen
10 × 1.00 = 10.00 cost of phosphoric acid
5 × .90 = 4.50 cost of potash
$27.00 cost of constituents

Fertilizer materials are commonly quoted to farmers at a ton price. For example, sulfate of ammonia may be quoted at $50 a ton, and nitrate of soda at $48. One way of determining which is the cheaper of the two materials would be to calculate the cost of a unit of nitrogen in each material. To do this, divide $50, the cost of sulfate of ammonia, by 21, the units of nitrogen contained. This gives $2.38, the cost of a unit of nitrogen. In the same way, $48 divided by 16, the units of nitrogen in nitrate of soda, gives $3 as the cost of a unit of nitrogen. Consequently, at the prices quoted, the sulfate of ammonia is a cheaper source of nitrogen than the nitrate of soda.

**B. Evaluate prices.** Prices of mixed fertilizers are commonly established semi-annually. They are spoken of as *spring prices* and *fall prices*. The price schedule is determined on the basis of a uniform unit price for each of the three plant-food constituents, plus a definite overhead charge for manufacture and sale of the product. To this must be added the margin for the local fertilizer dealer. For fertilizers purchased on time, it becomes necessary to make an additional charge to cover the cost of extending this credit. As a rule, dealers give a discount on carload orders. Consequently, in the purchase of mixed fertilizers it is essential not only that they be of high analysis, preferably having a total of at least 20 to 30 units of plant-food, but that they be purchased for cash and, when possible, in carload lots.

The fact that a mixed fertilizer is of high analysis does not necessarily mean that it is a good buy. Some high-analysis mixtures are, from the farmers' standpoint, relatively more expensive than certain of those in the low-analysis group. Price comparisons should be made between high-analysis mixtures before a final choice is made.

The 2–16–2 fertilizer is high in analysis and extensively recommended for the fertilization of grain. Nevertheless, it is an expensive mixture at present prices, having no great price advantage over the low-analysis 2–12–2. This is due to the fact that the mixture contains only four units of nitrogen and potash combined. Where this mixture is used in preference to superphosphate, the four units of nitrogen and potash must carry all the overhead cost of mixing, which makes them prohibitive in price for the grain crops.

Superphosphate (20 per cent) sells for about \$20 a ton, and the 2–16–2 analysis of mixed fertilizer for about \$35 a ton.[13] The 16 per cent of phosphoric acid in the 2–16–2 costs, as superphosphate, \$16 (4/5 × \$20). The two units of nitrogen and of potash cost in the 2–16–2 exactly \$19—(\$35 − \$16 = \$19). Expressed in terms of standard fertilizer materials, one secures for this \$19, the equivalent of 190 pounds of sulfate of ammonia and 67 pounds of 60 per cent muriate of potash. It is seldom that nitrogen and potash can be justified on grain crops at these prices. Where this is true, superphosphate is a better buy than the high-analysis 2–16–2. In making fertilizer recommendations this most important fact is overlooked.

The 4–16–4 mixture furnishes an additional two units each of nitrogen and potash. When selling for \$40 it costs only \$5 more a ton than the 2–16–2. Consequently, the additional four units of nitrogen and potash cost \$5, which in the 2–16–2 cost \$20. In order to secure nitrogen and potash at a reasonable price in mixed goods, it is necessary to purchase a mixture containing at least 8 per cent of either one, or of the two combined.

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[13] Prices for both superphosphate and mixed fertilizer vary in different sections and from year to year. Current, local prices may readily be substituted for those used in calculation.

Another price comparison between two mixed fertilizers of similar analysis is that between the 4–8–4 and the 5–10–5. These two mixtures contain the same relative amounts of the plant-food constituents; that is, the ratio of plant-food is the same. They differ in that the latter is 25 per cent more concentrated. It requires 2500 pounds, or 25 per cent more than a ton, of the 4–8–4 to equal one ton of the 5–10–5. Assume that the prices of these two mixtures are $30 and $35, respectively. The 5–10–5 costs $5 a ton more than the 4–8–4. For this $5 one secures in each ton of 5–10–5 an additional 500 pounds equivalent to a 4–8–4. In other words, the extra plant-food secured in the 5–10–5 costs at the rate of $20 a ton for the 4–8–4 instead of $30, the regular price of this analysis. At these prices a saving of nearly 7 per cent in the fertilizer bill results from the purchase of the 5–10–5 instead of the 4–8–4.

In purchasing mixed fertilizers, arrange to pay cash. Borrow from the bank rather than buy credit from the fertilizer manufacturer or dealer, and take advantage of all cash discounts. Select from the available high-analysis mixtures those that contain the desired proportion of the plant-food constituents, compare prices, and buy the analysis or the analyses furnishing plant-food at the lowest price. If the formula can be secured, give due consideration to its fitness to the crops that are to be fertilized. Take into consideration the residual effect on soil acidity. A worth-while saving can often be made through the coöperative buying of fertilizers. Particularly is this true in the purchase of fertilizing materials for home-mixing. A much lower price can generally be secured by purchasing the materials in carload lots. The individual farmer seldom has need for sufficient fertilizer in any given season to enable him to take advantage of this saving. However, if a number of farmers order collectively, they can all profit by the lower carload price. Frequently, dairy farmers pool their orders for superphosphate, and thereby save several dollars a ton. In some sections farmers' coöperative organizations are handling fertilizers as well as other farm supplies. Take advantage of any saving that can be made through the coöperative purchase of fertilizers.

**C. Choose, taking into consideration recommended practice.** In selecting the mixed fertilizer, whether factory-mixed or home-mixed, take into consideration all those factors which may influence the real agricultural value in relation to the cost. Consider also the suggestions made under the heading "Planning the fertilizer practice." Consult your agricultural college and your county agent and secure from them the latest information on fertilizer practices suited to your particular soil and cropping systems. These college and experiment-station workers have devoted much time to the study of soils and crops. As a result of practical as well as technical experiments, they have worked out very definite systems of fertilization for the different soils and the various crops and crop rotations. The fertilizer practices that they recommend take

Fig. 145. Fertilizer Experiments at the Rhode Island Experiment Station.

College and experiment-station workers have devoted much time to the study of soils and crops. As a result of experiments, they have worked out very definite systems of fertilization for the different soils and the various crop rotations.

## TABLE XXX

### Approved Fertilizers for Grains, Hay, and Silage for New York

(For feed-crop rotations and pastures apply fertilizer in amounts to supply an equivalent of 30 pounds of phosphoric acid a year.)

| Crop | Conditions | Analyses or Materials | Pounds per Acre |
|---|---|---|---|
| Corn for grain or silage, also for Millet and Sudan grass | Manured | Superphosphate 20%* | 150 |
| | Following legume sod and not manured | Superphosphate 20%* | 150 |
| | | 0–20–10 | 150 |
| | Not manured and not following legume sod | 10–20–10 | 150 |
| | | 5–10–5 | 300 |
| | | 6–18–6 | 175 |
| | | 4–12–4 | 250 |
| Oats, or spring barley, or mixture Seeded | Manured rotation | Superphosphate 20%* | 300 |
| | Rotation not manured | 5–20–5 | 300 |
| | | 4–16–4 | 375 |
| | | 5–20–10 | 300 |
| | | 3–12–6 | 500 |
| | | 0–20–10 | 300 |
| Buckwheat, oats or spring barley, or mixture Not seeded | Manured rotation | Superphosphate 20%* | 150 |
| | Rotation not manured | 5–20–5 | 150 |
| | | 4–16–4 | 200 |
| | | 5–20–10 | 150 |
| | | 3–12–6 | 250 |
| Wheat or rye Seeded | Manured | Superphosphate 20%* | 300 |
| | Following legume sod | Superphosphate 20%* | 300 |
| | | 0–20–10 | 300 |
| | Not manured and not following legume sod | 5–20–5 | 300 |
| | | 4–16–4 | 400 |
| | | 5–20–10 | 300 |
| | | 3–12–6 | 500 |
| | | 6–18–6 | 325 |
| | | 4–12–4 | 500 |

TABLE XXX—*Continued*

| Crop | Conditions | Analyses or Materials | Pounds per Acre |
|---|---|---|---|
| Wheat or rye Not seeded | Manured | Superphosphate 20%* | 250 |
| | Following legume sod | Superphosphate 20%*<br>0–20–10 | 300<br>300 |
| | Not manured and not following legume sod | 10–20–10<br>5–10–5<br>6–18–6<br>4–12–4<br>5–20–10<br>3–12–6 | 150<br>300<br>175<br>250<br>150<br>250 |
| Soybeans | Manured rotation or good soil | Superphosphate 20%* | 150 |
| | Poor soil, not recently manured | 5–20–5<br>4–16–4<br>5–20–10<br>3–12–6<br>0–20–10 | 200<br>225<br>200<br>325<br>200 |
| Alfalfa at time of seeding or as top-dressing | Manured rotation | Superphosphate 20%* | 400 |
| | Soil not recently manured | 0–20–10<br>0–20–20<br>0–12–12 | 400<br>400<br>650 |
| Timothy Fertilizer applied as top-dressing | Manured | Superphosphate 20%* | 150 |
| | Not manured | 10–10–10<br>7–7–7<br>Sulfate of ammonia † | 200<br>300<br>150 |

* If 30 or 32 per cent grade of superphosphate is used, apply about two-thirds as much.

† Other nitrogeneous materials may be substituted. Apply at rate to furnish from 20 to 40 pounds of nitrogen to the acre.

Note: For fertilizing corn grown in rotation see Chapter IX, N. Y. State Col. of Agr., Leaflet 9, January, 1940.

into consideration the factors emphasized as influencing the choice of mixed fertilizer. In many states fertilizer recommendations are revised annually, and made available in printed form to farmers and others who are interested. An example of such recommendations for field crops is given in Table XXX. Secure the recommendations of the local college and station, and use them as a guide in establishing fertilizer practices on your own farm. The fertilizer practices developed in Chapters IX to XII are based not only on the information available from experiments but also on the experience of many successful farmers.[14]

FIG. 146. FERTILIZER EXPERIMENTS AT THE NEW YORK STATE COLLEGE OF AGRICULTURE.

Secure the recommendations of the local college and station, and use them as a guide in establishing fertilizer practices on your own farm.

## 4. APPLYING MIXED FERTILIZERS

Mixed fertilizers should generally be applied just prior to or at the time of planting the crop. Where a crop occupies the land for several consecutive years, additional fertilizer may be applied as a top-dressing. In the fertilization of vegetable crops, where complete fertilizers are used, an application should be made for each crop grown. For grain, hay, and silage, where the fertilizer consists largely of superphosphate, or of superphosphate and potash, the application need be made but once or twice in a three-year to five-year rotation, provided, of course, that larger amounts are applied at the less-frequent intervals.

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[14] See Tables XLVII, XLIX, and L for mixed fertilizer recommendations for vegetables, fruits, and flowers.

**Procedure:**

A. Apply with drill.
B. Apply at proper rate.
C. Apply properly.

**A. Apply with drill.** Apply mixed fertilizers with a fertilizer drill or a lime distributor. Grain drills, as well as corn, potato, and cotton planters, are very commonly equipped with a fertilizer attachment through which the fertilizer is applied in conjunction with the planting of the seed. Use a lime distributor for making heavy applications of either superphosphate or mixed fertilizer. If a small area is to be fertilized, the material may be applied by hand.

**B. Apply at proper rate.** The rate at which fertilizer should be applied depends on the character of the crop, the intensity of production, the condition of the soil, and the frequency and method of application. In grain- and hay-crop rotations where mixed fertilizer is used, apply 200 to 400 pounds to the acre. In intensive vegetable-crop production, use 1000 pounds to a ton or more yearly. Irrespective of the rate of application, it is important that the fertilizer be distributed properly in the soil. If heavy applications are made, or if the fertilizer is especially concentrated, take greater precaution in its placement.

**C. Apply properly.** For best results, then, the fertilizer must be applied in the proper manner. The three common methods of application are: (1) applying in the row, (2) broadcasting, and (3) top-dressing. A combination of two methods, or sometimes all three methods, is often used. The practice to follow in applying fertilizer will depend on conditions as specified under each method of application.

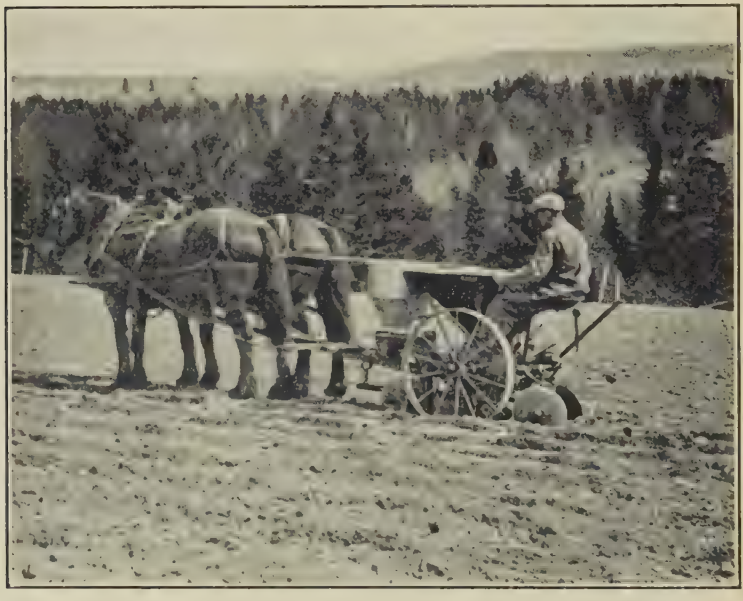

FIG. 147. APPLYING FERTILIZER FOR POTATOES. (International Harvester Co., Chicago.)

Grain drills as well as corn, potato, and cotton planters are very commonly equipped with a fertilizer attachment through which the fertilizer is applied in conjunction with the planting of the seed.

(1) *When to apply in the row.* When fertilizer is used for cultivated crops grown in rows or hills, such as corn, potatoes, and cotton, it may be applied in the row or hill, provided precaution is taken to prevent injury to the germinating seed. It has been found that injury results where a large amount of fertilizer is placed in direct contact with the seed. Such injury is not materially lessened where the fertilizer is

applied either above or below the seed. When it is distributed a half inch to an inch on either side of the seed, little if any injury results. It appears to make little difference whether the fertilizer is applied on both sides or all placed on one side of the seed.

Where a small amount of mixed fertilizer is used, best results will be secured on the immediate crop by applying in the row or hill. Not only is the loss of nitrogen by leaching less than with a broadcast application, but the plant receives greater stimulation in the early stages of growth. Reduced effectiveness due to fixation by the soil is kept at a minimum. Applications in excess of 300 to 400 pounds to the acre of fertilizer of standard concentration should not be made entirely in the row.

(2) *When to apply broadcast.* Where the application is heavy or where the fertilizer is being used not alone for the immediate crop but for several crops in the rotation, apply at least part of it broadcast. When it is applied by means of the fertilizer attachment of the small grain drill, the rows in which it is distributed are so close together that the effect is that of a broadcast application.

With a broadcast application there is little if any danger of injuring the seed. Relatively heavy applications can be made with safety. The residual effect on the following crop is uniform. Except with a fertilizer high in nitrogen, there is little loss of plant-food through leaching, and only in soils with high-fixation power is there any great reduction in the effectiveness of the phosphoric acid and potash.

Many farmers fail to appreciate the tremendous residual effect from a liberal fertilizer application. Instead they expect the full benefit on the crop fertilized. It has been found in field-crop production that from 40 to 50 per cent of the value of the fertilizer results from its residual effect. It is a good practice to fertilize cash crops liberally, and to let the other crops of the rotation depend on the residual effect of the fertilizer. Where land is seeded down to hay, apply a sufficient amount of the mineral constituents for the nurse crop to last through one or two years of hay. In either event, incorporate the fertilizer uniformly with the surface soil to assure a uniform residual effect.

(3) *Conditions justifying top-dressing.* It is sometimes desirable to apply fertilizer as a top-dressing to the growing crop. This becomes necessary in fertilizing lawns, or crops such as alfalfa or timothy which occupy the land for several years and which have not been adequately fertilized when seeded. If a crop occupies the land for a single season, apply the fertilizer prior to or at the time of seeding.

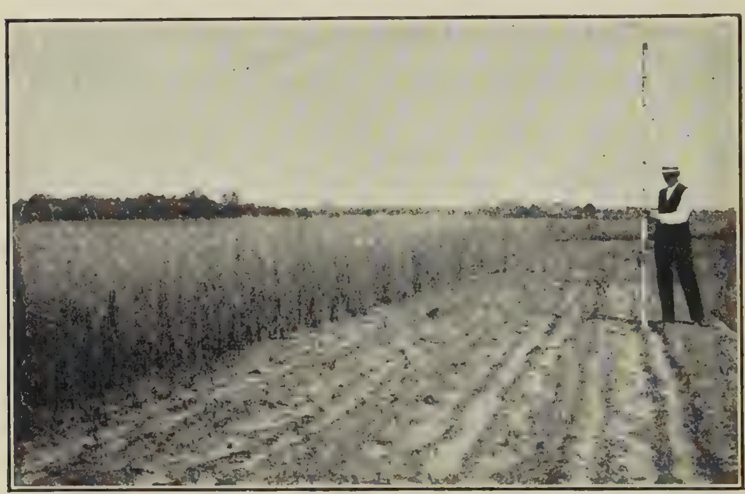

FIG. 148. RESIDUAL EFFECT OF COTTON FERTILIZER ON RYE.

Many farmers fail to appreciate the tremendous residual effect from a liberal fertilizer application. Instead they expect the full benefit on the crop fertilized.

In the fertilization of vegetables it is often desirable to withhold part of the fertilizer and apply it later in the season. When the top-dressing is applied along the sides of the row, the practice is spoken of as *side-dressing,* and when applied in a circle around the individual plants, as *spot-application.* Field-grown rowed crops are sometimes side-dressed, but the practice should be confined largely to vegetable or other high-value crops. The main advantage of top-dressing is that less nitrogen is lost through leaching. There is no justification for withholding part of the phosphoric acid and potash to be used as a top-dressing. If a top-dressing is made, it should consist of a soluble form of nitrogen such as nitrate of soda.

Where fertilizer is applied as a top-dressing to growing crops, care must be taken not to "burn" the foliage. Apply when the plants are dry, preferably just preceding a rain. In applying to vegetables, do not permit the fertilizer to come in contact with the leaves or stalks. For vegetables, apply as a side-dressing, covering a strip about 6 inches wide, starting several inches from either side of the row, or as a spot-application around the individual plants. Distributors are available for the row- or the spot-application of fertilizer.

### 5. Home-Mixing Fertilizers

Fertilizers can be mixed satisfactorily on the farm. When the mixing is properly done, a home-mixed fertilizer is equal in all respects to one of the same analysis mixed in a fertilizer factory. Where a considerable amount of fertilizer is used, or where a number of farmers pool their orders for the materials, as much as $5 to $8 a ton can often be saved by home-mixing. Where mixed fertilizers with a concentration of 30 per cent or more of plant-food are used, little saving will result from home-mixing. The practice also has a distinct educational value. Invariably, in sections where fertilizers are extensively home-mixed, farmers are better informed as to the character and value of fertilizers. Home-mixing also enables the user to know exactly what the fertilizer mixture contains. This is not true of mixed goods, except those sold on the open-formula basis. It is often claimed that the mixing can be done more cheaply and more thoroughly in a large factory than on a barn floor. The results of experiments, as well as the experiences of farmers, prove that a satisfactory mixture can be produced at home, and at a saving. If only a few tons of fertilizer are used annually, home-mixing offers little saving unless the chemicals can be purchased through a cooperative pool.

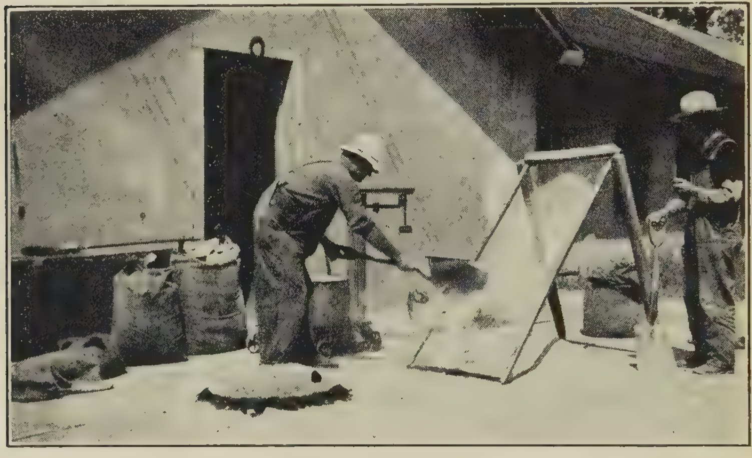

FIG. 149. HOME-MIXING FERTILIZER.

When the mixing is properly done, a home-mixed fertilizer is equal in all respects to one of the same analysis mixed in a fertilizer factory.

**Procedure:**

A. Choose the plant-food materials.
B. Determine the formula.
C. Calculate the cost.
D. Mix the materials.

**A. Choose the plant-food materials.** It is unnecessary to use more than six or eight fertilizer materials in home-mixing. Normally, the phosphoric acid should be secured from superphosphate, and the potash from muriate of potash. If the fertilizer is to be used for tobacco or sugar beets, replace part of the muriate with sulfate of potash to prevent excess chlorine in the mixture. Supply part of the nitrogen by using nitrate of soda or sulfate of ammonia. In most instances both materials should be used. In addition, a conditioner or drier, such as animal tankage, dried ground-fish scrap, dried blood, or cotton-seed meal, should be added, for otherwise the mixture would harden on standing. By applying the fertilizer immediately after mixing, the conditioner may be eliminated, and the mixture still applied with the ordinary fertilizer drill. However, it is safer always to use 300 to 400 pounds to the ton of some one of the materials mentioned as being effective conditioners. Since all contain nitrogen, their use will reduce the amount of nitrate of soda and sulfate of ammonia needed. Tankage, fish scrap, and cotton-seed meal also contain phosphoric acid, and the last, potash as well. Make allowance for this additional plant-food in calculating the formula. The use of granular superphosphate, or ammo-phos, reduces the need for a mechanical conditioner.

Do not use burned or hydrated lime, ashes, basic slag, cyanamid, or other material containing lime, in the home mixture, since such materials tend to cause a reversion of the available phosphoric acid and the liberation of ammonia from sulfate of ammonia. In some instances as much as 25 pounds of hydrated lime or 50 pounds of limestone have been added to the ton of superphosphate by the manufacturers. Additional lime, added when the fertilizer is mixed, might materially lessen its immediate effectiveness, owing to reversion of the phosphoric acid; and its ultimate value might be reduced as the result of loss of ammonia. Dolomitic limestone may be added when a non-acid-forming fertilizer is needed.

It is desirable to secure the nitrogen from several sources. Some will normally be supplied by the conditioner; the remainder should be secured largely from nitrate of soda and sulfate of ammonia.

**B. Determine the formula.** The amounts of the different materials which should be used for a given analysis can readily be determined. The following example will make the procedure clear:

A 4–8–4 fertilizer contains 4 per cent of nitrogen, 8 per cent of available phosphoric acid, and 4 per cent of soluble potash. In other words, each hundred pounds of the fertilizer contains 4 pounds of nitrogen, 8 pounds of available phosphoric acid, and 4 pounds of soluble potash. Since there are 20 hundred pounds in a ton, 20 times these amounts—80, 160, and 80 pounds, respectively—would be required for a ton of 4–8–4 analysis. In order to prevent lumping, 400 pounds of tankage, containing 10 per cent nitrogen and 5 per cent available phosphoric acid, are used. This tankage would furnish 40 pounds of nitrogen and 20 pounds of available phosphoric acid. Besides the tankage, sulfate of ammonia, analyzing 21 per cent nitrogen and 16 per cent superphosphate, and muriate of potash, analyzing 50 per cent potash, are used. Deducting the nitrogen, and phosphoric acid furnished by the tankage, there remain 40 pounds of nitrogen, 140 pounds of phosphoric acid, and 80 pounds of potash to be supplied by these other constituents. It would require as many hundred pounds of sulfate of ammonia to furnish the 40 pounds of nitrogen as 21 is contained in 40, which is 1.9 hundred pounds. The number of pounds would be 100 times 1.9, or 190 pounds of sulfate of ammonia. By the same process, the amount of superphosphate and of muriate of potash may be determined. The procedure may be expressed as follows:

40 ÷ 21 = 1.9 1.9 × 100 = 190 pounds sulfate of ammonia
140 ÷ 16 = 8.75 8.75 × 100 = 875 pounds superphosphate
80 ÷ 50 = 1.60 1.60 × 100 = 160 pounds muriate of potash
400 pounds tankage
1625 pounds total weight

The total weight of the materials used in this formula for equivalent of a ton of a 4–8–4 would be 1625 pounds. In order that the mixture may conform to the 4–8–4 analysis, 375 pounds of filler must be added. It is needless to add this filler in home-mixing, since it is not necessary that the exact concentration of the fertilizer be secured. Without filler, the proper ratio of nitrogen, phosphoric acid, and potash, viz., 1–2–1, has been obtained. In plant-food content, the 1625 pounds is exactly equivalent to 2000 pounds of the desired 4–8–4. By reducing proportionately the rate of application, the same amount of plant-food can be applied to the acre with the home mixture, to which filler has not been added, as with the 4–8–4.

Suppose, for example, the 4–8–4 fertilizer is to be applied at the rate of 500 pounds, or ¼ of a ton, to the acre. Since the 1625 pounds of the home mixture is equal to 2000 pounds of a 4–8–4, by applying ¼ of 1625 pounds, or 406¼ pounds, of the home mixture without filler, the identical fertilization would be given the acre of land. If the filler is left out, the analysis of the mixture would be approximately 5–10–5 instead of 4–8–4. Formulas can be secured from the agricultural colleges and experiment stations for the home-mixing of a fertilizer of any desired analysis.[15]

**C. Calculate the cost.** In order to determine the saving made possible by home-mixing, it is necessary to calculate the exact cost of a home-mixed fertilizer. This is not a difficult procedure. Following is the method for determining the cost of the home-mixed 4–8–4.

The following ton prices are assumed for the fertilizing materials used:

| | |
|---|---|
| Animal tankage | $40 |
| Sulfate of ammonia | 50 |
| Superphosphate | 20 |
| Muriate of potash | 50 |

Calculate the cost as follows:

400/2000 × $40 = $8.00 cost of 400 pounds tankage
190/2000 × $50 = $4.75 cost of 190 pounds sulfate of ammonia
875/2000 × $20 = $8.75 cost of 875 pounds superphosphate
160/2000 × $50 = $4.00 cost of 160 pounds muriate of potash
$25.50 total cost of ton equivalent

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[15] See General Information at end of chapter for additional formulas for home-mixing.

The necessary materials for the 1625 pounds of home mixture, which is equivalent to 1 ton of a 4–8–4, cost $25.50. To this figure should be added the labor cost of mixing, which is generally about $1 a ton. By subtracting this total cost of the ton equivalent of the home mixture from the price of a ton of the factory-mixed 4–8–4, the saving offered by home-mixing will be ascertained.

**D. Mix the materials.** The actual mixing of the fertilizer materials is a simple operation. Expensive machinery is unnecessary if the materials are dry and free from lumps. The ordinary scoop shovel and a screen, made of four meshes to the linear inch galvanized netting, are the only equipment needed. Provide platform scales for weighing the material, unless the ingredients are purchased in sacks. If in sacks, the approximate amount of each material is determined by taking a fraction of a full sack of known weight.

Mix on the barn floor or in a tight wagon box. The material used in largest quantity is first spread out in the amount needed for the batch which is to be mixed. This would invariably be the superphosphate. Then the other materials are added in alternate layers, and the mass shoveled over until it is of a uniform color, indicating thorough mixing. When the fertilizer is to be used within a few days, screen and sack at once. Otherwise throw it to one side in a large pile and screen and bag as it is needed. Break up any lumps not passing the screen, by pounding with the back of the shovel. If serious lumping should occur, use a wooden tamper. Where home-mixing is done on a large scale, provide a small mill for grinding lumpy materials, and mix with a concrete mixer.

## GENERAL INFORMATION

### 1. Fertilizer Materials[16]

**A. Materials furnishing nitrogen.** *Nitrate of soda* is one of the most extensively used nitrogenous materials. There are two sources, one a natural salt deposit in Chile, and the other a manufactured product in which the nitrogen is secured from the air. There is little difference in either composition or agricultural value between Chilean and synthetic nitrate of soda. The salt is soluble in water, and the nitrogen is immediately available for plants. It contains an average of 16 per cent nitrogen, equivalent to nearly 18 per cent of ammonia. It is one of the very best nitrogenous fertilizers and is an especially desirable source of nitrogen for application to the growing plant, or, in fact, wherever a soluble, quick-acting material is desired. It has a slightly alkaline effect on the soil. On sandy soils there is some danger of loss of nitrogen by leaching when nitrate of soda is used, and reasonable precautions should be taken to prevent such loss.

*Sulfate of ammonia* is a by-product resulting from the manufacture of illuminating gas and of coke. Like nitrate of soda, it is a water-soluble salt, in which the nitrogen is readily available, though it acts somewhat more slowly. It has an acidifying residual effect on the soil which may be neutralized in farm practice by applying lime. Sulfate of ammonia is very uniform in composition, containing 20½ to 21 per cent of nitrogen.

*Dried blood and tankage* are slaughter-house by-products. They carry nitrogen in the organic form, and more or less phosphoric acid. It is frequently claimed that the nitrogen in these animal products is more valuable than that in nitrate of soda or sulfate of ammonia, but this contention has not been verified in the results of experiments with these different materials. High-grade blood contains 12 to 14 per cent nitrogen. Tankage is so variable that it should be purchased only on a strictly guaranteed analysis. The better grade of blood tankage contains 8 to 10 per cent nitrogen and 7 to 8 per cent phosphoric acid. Bone tankage contains less nitrogen and more phosphoric acid than blood tankage. In addition to nitrogen, these animal by-products contain some phosphoric acid. *Fish scrap* is a by-product of the fish industry, and is similar in composition and value to blood tankage.

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[16] See Table XXXI for list of fertilizer materials, their composition, and effect on soil acidity.

*Cyanamid, calcium nitrate, urea, calurea, cal-nitro, and leunasalpeter* are commercial materials manufactured from atmospheric nitrogen. They are not well adapted to home-mixing, but are successfully used in ready-mixed fertilizers.

Various other commercial materials, containing more or less nitrogen, are utilized in fertilizers. Cotton and castor-bean meals, muck and dried manures of various kinds, are common examples. Garbage tankage and other low-grade organic materials are used to some extent in factory-mixed fertilizers.

**B. Materials furnishing phosphorus or phosphoric acid.** *Superphosphate,* sometimes called *acid phosphate* or *acid rock,* is the material most extensively used to furnish phosphorus or phosphoric acid. It is manufactured from rock phosphate by first grinding and then treating with sulfuric acid. The phosphoric acid is in a soluble form, and is readily available. There are several grades on the market, containing 16 to 20 per cent of available phosphoric acid. Double superphosphate and treble superphosphate are even more concentrated materials made from phosphate rock. They contain 30 to 45 per cent phosphoric acid. The 20 per cent grade of superphosphate contains about 50 per cent gypsum, or land plaster. This gypsum supplies sufficient sulfur to meet any possible needs for this constituent. In the 30 per cent grade, and in grades of greater concentration, the gypsum has been largely removed. Most grades are obtainable in either the powdered or the granular form.

*Rock phosphate,* sometimes called *floats,* is simply the raw phosphate rock ground to a fine powder. The phosphorus in this material is not readily available to plants. When it is finely ground and applied with farm manure, satisfactory results are generally secured. It contains 28 to 32 per cent of phosphoric acid. Rock-phosphate deposits occur in Florida, South Carolina, and Tennessee. Extensive deposits occur in the states of Montana, Idaho, Wyoming, and Utah and are being used to some extent.

FIG. 150. A ROCK-PHOSPHATE MINE. (F. C. Bauer, University of Illinois.)

Rock-phosphate deposits occur in Florida, South Carolina, and Tennessee. Extensive deposits occur in the states of Montana, Idaho, Wyoming, and Utah.

*Basic slag* is a by-product in the manufacture of steel. Imported slag contains 16 to 20 per cent of phosphoric acid, most of which is in a form more readily available than that in rock phosphate, but not so available as that in superphosphate. It has some value as a liming material. It is not used to any great extent by American farmers. American slag, from the Birmingham, Alabama, iron deposits, contains 8 to 11 per cent phosphoric acid. Slag from other domestic sources contains little or no phosphorus, but is used to some extent as a liming material.

*Bone meal* is a good source of phosphoric acid, but the tendency in the past has been to give it too high an agricultural valuation in comparison with superphosphate and the other phosphatic materials. Bone meal has been put on the market in several forms. The raw bone meal, which is merely ground untreated bones, contains abut 23 per cent phosphoric acid and 3½ per cent nitrogen. Steamed bone meal contains 1 to 2 per cent more phosphoric acid, but only 1 to 2 per cent nitrogen. The phosphoric acid in steamed bone meal is somewhat more available than that in the raw bone meal.

FIG. 151. GERMAN POTASH MINE. (N. V. Potash Export My.)

A considerable portion of the potash used in commercial fertilizers formerly came from the extensive deposits of potash salts in Germany and France.

**C. Materials furnishing potassium or potash.** A considerable portion of the potash used in commercial fertilizers formerly came from the extensive deposits of potash salts in

Germany and France. Within recent years, domestic sources have been developed in New Mexico and California and are now capable of supplying a large proportion of our needs. As mined, these salts are impure, but they are partially refined before being put on the market. The four important potash salts which are used in the United States are muriate of potash, sulfate of potash, kainit, and manure salt. All four materials carry the potash in a water-soluble form. Fortunately, the soil has the power of fixing potash, so that even when it is applied in the form of soluble salts there is relatively little loss through leaching.

*Muriate of potash* is the common chloride form, and contains 50 to 60 per cent of potash. In addition, it contains a considerable amount of common salt. It is the most common potash material used in the home-mixing of fertilizers. On account of the chlorine content, it should be used in restricted amounts for tobacco and sugar beets.

*Sulfate of potash* contains about the same amount of potash as muriate. It invariably sells at a higher price, but has never been shown to be superior to the muriate, except for a few crops.

*Kainit* and *manure salt* are lower in composition than the muriate and sulfate. They contain 12 to 14 and 20 per cent, respectively, of potash.

*Wood ashes* furnish another minor source of potash. Unleached, hardwood ashes contain about 6 per cent of potash in a fairly available form. They also contain an equivalent of about 1000 pounds of limestone or about 500 pounds of burned lime to the ton. Ordinarily, the price of wood ashes is too high to justify their use on the general farm crops.

**D. Concentrated materials.** A number of new materials, concentrated in composition, such as *ammonium nitrate, ammophos,* and *urea,* are now on the market. They are largely the result of recent advancement and expansion in the commercial fixation of atmospheric nitrogen. Their composition, along with that of the standard materials, is given in Table XXXI.

## TABLE XXXI

### Composition of Fertilizer Materials

| Fertilizer materials | Source | Composition | | | Availability | Toxic effects* | Mechanical properties† | Residual effect upon soil | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Nitrogen (N) | Phosphoric acid ($P_2O_5$) | Potash ($K_2O$) | | | | Reaction | Limestone required to neutralize the residual acidity from one ton of material | Limestone equivalent to the residual alkalinity from one ton of material |
| | | | | | | | | | *Pounds* | *Pounds* |
| Blood | Animal | 12 to 14 | ........ | ........ | Slowly | 1 | A | Acid | 457 | .......... |
| Calcium nitrate | Synthetic | 15 | ........ | ........ | Soluble | 1 | C | Slightly alkaline | .......... | .......... |
| Cal-nitro | Synthetic | 16 and 20 | ........ | ........ | Soluble | 1 | C | Alkaline | .......... | .......... |
| Calurea | Synthetic | 34 | ........ | ........ | Soluble | 1 | C | Acid | 1200 | .......... |
| Cocoa shell meal | Vegetable | 2¾ to 3 | ........ | ........ | Very slowly | 0 | A | Slightly alkaline | .......... | 33 |
| Cyanamid | Synthetic | 22 | ........ | ........ | Available | 2 | A | Alkaline | .......... | 1245 |
| Leunasalpeter | Synthetic | 26 | ........ | ........ | Soluble | 1 | C | Acid | .......... | .......... |
| Nitrate of ammonia | Manufactured | 35 | ........ | ........ | Soluble | 1 | C | Acid | 1250 | .......... |
| Nitrate of soda "Arcadian" | Synthetic | 16 | ........ | ........ | Soluble | 1 | C | Alkaline | .......... | 583 |
| Nitrate of soda "Chilean" | Natural | 16 | ........ | ........ | Soluble | 1 | C | Alkaline | .......... | 583 |
| Sulfate of ammonia | By-product | 20½ to 21 | ........ | ........ | Soluble | 1 | B | Acid | 2249 | .......... |
| Urea | Synthetic | 46 to 46½ | ........ | ........ | Soluble | 1 | C | Acid | 1680 | .......... |
| Basic slag (imported) | By-product | ........ | 16 to 20 | ........ | Available | 0 | B | Alkaline | .......... | 1480 |
| Rock phosphate | Natural | ........ | 32 to 36 | ........ | Very slowly | 0 | B | Alkaline | .......... | 1122 |
| Superphosphate | Manufactured | ........ | 16 to 20 | ........ | Available | 1 | C | Neutral | .......... | .......... |
| Superphosphate (double or treble) | Manufactured | ........ | 40 to 45 | ........ | Available | 1 | C | Neutral | .......... | .......... |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Fish scrap | Animal | 6 to 8 | 8 | ........ | Slowly | 0 | A | Slightly acid | 100 | ........ |
| Fish scrap (acidulated) | Animal | 6 to 7 | 6 | ........ | Available | 1 | A | Slightly acid | 100 | ........ |
| Garbage tankage | Vegetable and animal | 2½ to 3 | 1½ to 3 | ¾ to 1½ | Very slowly | 0 | A | Alkaline | ........ | 134 |
| Nitrogeneous tankage | Animal and vegetable | 6 to 9 | ........ | ........ | Slowly | 0 | A | Acid | 320 | ........ |
| Peat and muck | Vegetable | 1 | ........ | ........ | Very slowly | 0 | A | Neutral or acid | ........ | ........ |
| Tobacco stems | Vegetable | 2 to 3 | ½ to 1 | 5 to 10 | Slowly | 0 | A | Neutral | ........ | 500 |
| *Mineral phosphoric acid carriers* | | | | | | | | | | |
| Ammo-phos | Manufactured | 11 | 48 | ........ | Available | 1 | C | Acid | 1097 | ........ |
| Ammoniated superphosphate | Manufactured | 2 | 18 | ........ | Available | 1 | C | Acid | 115 | ........ |
| Basic slag (imported) | By-product | ........ | 16 to 20 | ........ | Available | 0 | B | Alkaline | ........ | 1015 |
| Bone ash | Animal | ........ | 30 to 40 | ........ | Slowly available | 0 | A | Alkaline | ........ | 1413 |
| Rock phosphate | Natural | ........ | 32 to 36 | ........ | Very slowly | 0 | B | Alkaline | ........ | 200 |
| Superphosphate (powdered) | Manufactured | ........ | 16 to 45 | ........ | Available | 1 | C | Neutral | ........ | ........ |
| Superphosphate (granular) | Manufactured | ........ | 20 to 32 | ........ | Available | 1 | A | Neutral | ........ | ........ |
| *Organic phosphoric acid carriers* | | | | | | | | | | |
| Bone tankage | Animal | 5 to 6 | 14 | ........ | Slowly | 0 | A | Neutral | ........ | ........ |
| Steamed bone meal | Animal | 1 to 2 | 20 to 25 | ........ | Slowly | 0 | A | Alkaline | ........ | 500 |
| *Potash carriers* | | | | | | | | | | |
| Kainit | Natural | ........ | ........ | 12 to 14 | Available | 1 | C | Neutral | ........ | ........ |
| Manure salt | Natural | ........ | ........ | 20 to 40 | Available | 1 | C | Neutral | ........ | ........ |
| Muriate of potash | Natural | ........ | ........ | 50 to 60 | Available | 1 | C | Neutral | ........ | ........ |
| Nitrate of potash | Manufactured | 12 to 14 | ........ | 44 to 46 | Available | 1 | C | Alkaline | ........ | ........ |
| Nitrophoska | Manufactured | 15 | 30 | 15 | Available | 1 | C | Acid | ........ | ........ |
| Sulfate of potash | Natural | ........ | ........ | 50 | Available | 1 | C | Neutral | ........ | ........ |
| Wood ashes | Vegetable | ........ | 1 to 2 | 1 to 5 | Available | 0 | B | Alkaline | ........ | 500 to 1000 |

0: There is no danger of toxic injury. 1: Toxic injury may result from the use of relatively large amounts applied directly to crops or from smaller amounts applied with seed. 2: Relatively small amounts may be toxic.

* Cornell Extension Bulletin 281.

† A: Does not harden, and tends to improve the physical condition of a mixture. B: Has but little effect, either beneficial or harmful, upon the mechanical condition of a fertilizer in which it is used. C: Has a tendency to harden or to cause hardening in a mixture.

### 2. Simplified Soil and Crop Tests for Determining Fertilizer Needs

Various simplified methods of testing soils and crops to determine deficiencies in available plant nutrients have been developed. Such tests may be of value as an additional source of information in the development of long-time fertilizer programs, but they are unreliable as a basis on which to determine the analysis or the amount of fertilizer which would prove most profitable for a single crop. Unfortunately, there is a tendency to use them for the latter rather than for the former purpose. Do not be misled, believing that as a result of these simplified tests you can determine the best fertilizer to use.

### 3. Fertilizer Tables for Home-Mixing

In working out a fertilizer formula, useful information is available in tabulated form. Tables XXXII and XXXIII are representative, and should prove of help in calculating formulas.

### 4. Fertilizer Formulas for Home-Mixing

Representative formulas are given for some of the more common analyses. These formulas can safely be followed in home-mixing. They contain sufficient conditioner to prevent lumping and to give the mixture good drilling qualities.

5–10–5

200 pounds of nitrate of soda
200 pounds of sulfate of ammonia
400 pounds of animal tankage
900 pounds of superphosphate (20 per cent)
200 pounds of muriate of potash (50 per cent)

1900 pounds total, equivalent to 1 ton of 5–10–5

## TABLE XXXII

(The amount of any of the common fertilizer materials required to make up a particular formula may be determined at a glance.)

| Proportion of Plant-Food in Desired Analysis | Nitrogen Derived from | | | | | | Phosphoric Acid Derived from | | | | | Potash Derived from | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nitrate of Soda (16 per cent) | Sulfate of Ammonia (20.5 per cent) | Bone Tankage or Castor Bean Meal (6 per cent) | Animal Tankage (10 per cent) | Fish Scrap (8½ per cent) | Garbage Tankage (2.5 per cent) | Superphosphate (16 per cent) | Superphosphate (18 per cent) | Double Superphosphate (40 per cent) | Steamed Bone Meal (22 per cent) | Bone Tankage (14 per cent) | Muriate or Sulfate (50 per cent) | Manure Salt (20 per cent) | Kainit (12 per cent) |
| Per Cent | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds | Pounds |
| 1 | 125 | 98 | 333 | 200 | 235 | 800 | 125 | 111 | 50 | 91 | 143 | 40 | 100 | 167 |
| 2 | 250 | 195 | 667 | 400 | 471 | 1600 | 250 | 222 | 100 | 182 | 286 | 80 | 200 | 333 |
| 3 | 375 | 293 | 1000 | 600 | 706 | ...... | 375 | 333 | 150 | 273 | 429 | 120 | 300 | 500 |
| 4 | 500 | 390 | 1333 | 800 | 941 | ...... | 500 | 444 | 200 | 364 | 571 | 160 | 400 | 667 |
| 5 | 625 | 438 | 1667 | ...... | 1177 | ...... | 625 | 555 | 250 | 455 | 714 | 200 | 500 | 833 |
| 6 | 750 | 585 | 2000 | ...... | 1412 | ...... | 750 | 666 | 300 | 545 | 857 | 240 | 600 | 1000 |
| 7 | 875 | 682 | ...... | ...... | 1647 | ...... | 875 | 778 | 350 | 636 | 1000 | 280 | 700 | 1167 |
| 8 | 1000 | 730 | ...... | ...... | 1882 | ...... | 1000 | 889 | 400 | 727 | 1143 | 320 | 800 | 1333 |
| 9 | 1125 | 878 | ...... | ...... | ...... | ...... | 1125 | 1000 | 450 | 818 | 1286 | 360 | 900 | 1500 |
| 10 | 1250 | 976 | ...... | ...... | ...... | ...... | 1250 | 1111 | 500 | 909 | 1429 | 400 | 1000 | 1667 |
| 11 | 1375 | 1073 | ...... | ...... | ...... | ...... | 1375 | 1222 | 550 | 1000 | 1571 | 440 | 1100 | 1833 |
| 12 | 1500 | 1171 | ...... | ...... | ...... | ...... | 1500 | 1333 | 600 | 1091 | 1714 | 480 | 1200 | 2000 |

Example: Assuming that a 2–12–2 mixture is desired, a fertilizer of this composition would contain 2 per cent nitrogen, 12 per cent phosphoric acid, and 2 per cent potash. In each ton there would be 40, 240, and 40 pounds of nitrogen, phosphoric acid, and potash, respectively. This would be furnished by 400 pounds of animal tankage, 1500 pounds of 16 per cent superphosphate, and 80 pounds of muriate of potash. This would make a total of 1980 pounds equivalent to 2000 pounds of a 2–12–2 mixture. The addition of 20 pounds of filler would make a full ton of the composition desired. Without filler, 99 pounds of the home-mixture would equal 100 pounds of the ready-mixed goods.

## TABLE XXXIII

(Showing the percentage of nitrogen, phosphoric acid, and potash furnished by 100 pounds of fertilizer material.)

| Fertilizer Material | Composition | Nitrogen, Per Cent | Phosphoric Acid, Per Cent | Potash, Per Cent |
|---|---|---|---|---|
| Nitrate of soda | 16 per cent nitrogen | 0.8 | ........ | ........ |
| Sulfate of ammonia | 20 per cent nitrogen | 1.03 | ........ | ........ |
| Dried blood | 13 per cent nitrogen | 0.65 | ........ | ........ |
| Animal tankage | 10 per cent nitrogen, 8 per cent phosphoric acid | 0.5 | 0.4 | ........ |
| Bone tankage | 6 per cent nitrogen, 14 per cent phosphoric acid | 0.3 | 0.7 | ........ |
| Dried fish scrap | 8.5 per cent nitrogen, 8 per cent phosphoric acid | 0.43 | 0.4 | ........ |
| Cotton-seed meal | 7 per cent nitrogen, 3 per cent phosphoric acid, 1.7 per cent potash | 0.35 | 0.15 | 0.085 |
| Superphosphate | 16 per cent phosphoric acid | ........ | 0.8 | ........ |
| Superphosphate | 18 per cent phosphoric acid | ........ | 0.9 | ........ |
| Superphosphate | 20 per cent phosphoric acid | ........ | 1.0 | ........ |
| Steamed bone meal | 25 per cent phosphoric acid, 1 per cent nitrogen | 0.05 | 1.25 | ........ |
| Muriate of potash | 50 per cent potash | ........ | ........ | 2.50 |
| Sulfate of potash | 50 per cent potash | ........ | ........ | 2.50 |
| Kainit | 12 per cent potash | ........ | ........ | 0.6 |
| Manure salt | 20 per cent potash | ........ | ........ | 1.0 |

Explanation: To determine the composition of a mixture, multiply the hundreds of pounds of each material by factors given. A mixture of 400 pounds of animal tankage, 200 pounds of nitrate of soda, 1200 pounds 16 per cent superphosphate, and 200 pounds muriate of potash would have a composition represented by the analysis 3.6–11.2–5.

$4 \times 0.5 = 2$ per cent nitrogen from tankage.
$4 \times 0.4 = 1.6$ per cent phosphoric acid from tankage.
$2 \times 0.8 = 1.6$ per cent nitrogen from nitrate of soda.
$12 \times 0.8 = 9.6$ per cent phosphoric acid from superphosphate.
$2 \times 2.5 = 5$ per cent potash from muriate of potash.
$2 + 1.6 = 3.6$ per cent nitrogen from tankage and nitrate.
$1.6 + 9.6 = 11.2$ per cent phosphoric acid from tankage and superphosphate.
5 per cent potash from muriate of potash.

10–20–10

250 pounds of nitrate of soda
350 pounds of sulfate of ammonia
250 pounds of animal tankage
750 pounds of ammo-phos (11–48 per cent)
400 pounds of muriate of potash (50 per cent)
2000 pounds

4–16–4

100 pounds of nitrate of soda
200 pounds of sulfate of ammonia
240 pounds of animal tankage
1000 pounds of superphosphate (20 per cent)
200 pounds of ammo-phos (11–48 per cent)
160 pounds of muriate of potash (50 per cent)
1900 pounds, equivalent to 1 ton of 4–16–4

These three mixtures, like most factory-mixed fertilizers, will have a slight acidifying effect on the soil. The following formula would be classed as non-acidifying:

5–10–5

125 pounds of nitrate of soda
200 pounds of sulfate of ammonia
300 pounds of animal tankage
175 pounds of ammo-phos (11–48 per cent)
500 pounds of superphosphate (20 per cent)
200 pounds of muriate of potash (50 per cent)
300 pounds of dolomitic limestone
1800 pounds, equivalent to 1 ton of 5–10–5

## 5. Storage of Mixed Fertilizers

Not only are superphosphate and other fertilizer materials subject to lumping or hardening on standing, but mixed fertilizers, even those containing mechanical conditioners, may harden unless properly stored. Fertilizers should never be stored on earth floors or in damp places. Even when stored on concrete floors, unless very dry, boards should be placed under the bags. If floor space will permit, the sacks should be set on end. Never put the bags in high piles, as pressure on the bottom sacks will tend to harden the fertilizer. It is not a good plan to carry fertilizer over from one year to the next, for even though the fertilizer may not harden, the bags may disintegrate. So long as the fertilizer remains dry there will be virtually no loss of its fertilizing value during storage.[17]

## 6. Factors to Use in Interpreting the Guaranteed Analysis of Fertilizers

In the purchase of fertilizers the composition may not be given in terms of nitrogen, phosphoric acid, and potash. It is customary with certain materials, such as bone meal and animal tankage, to give the phosphorus content as tricalcium phosphate (often called bone phosphate of lime, and abbreviated BPL) instead of phosphoric acid. In the same way, the composition of nitrogenous materials may be expressed in terms of ammonia instead of nitrogen. The following factors may be needed for the full understanding of the chemical composition of fertilizers.

### Factors for Converting Elements and Compounds Used in the Fertilizer Industry

To change ammonia to equivalent of nitrogen, multiply by 0.82.

To change nitrogen to equivalent of ammonia, multiply by 1.20.

To change phosphorus to equivalent of phosphoric acid, multiply by 2.30.

To change phosphorus to equivalent of bone phosphate of lime, multiply by 5.00.

To change phosphoric acid to equivalent of phosphorus, multiply by 0.44.

To change phosphoric acid to equivalent of bone phosphate of lime, multiply by 2.20.

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[17] See page 299 for information on preventing the lumping of superphosphate.

To change bone phosphate of lime to equivalent of phosphorus, multiply by 0.20.

To change bone phosphate of lime to equivalent of phosphoric acid, multiply by 0.46.

To change potassium to equivalent of potash, multiply by 1.20.

To change potash to equivalent of potassium, multiply by 0.83.

To change potash to equivalent of muriate of potash, multiply by 1.60.

To change potash to equivalent of sulfate of potash, multiply by 1.85.

## 7. REPRESENTATIVE STATE FERTILIZER LAW

The fertilizer laws of the various states are similar. An abstract is given of the law for New York State as being representative. Secure information relative to the requirements of the local state law dealing with the manufacture and sale of commercial fertilizers.

### Requirements of New York's Fertilizer and Lime Law

*Statements to be attached to packages.* No manufacturer, firm, association, corporation or person shall sell, offer or expose for sale in this state any commercial fertilizer or any material to be used as fertilizer, except animal manures which have not been artificially treated or manipulated, unless such commercial fertilizer or material to be used as a fertilizer shall be accompanied by or shall have affixed to each and every package in a conspicuous place on the outside thereof, a plainly printed statement which shall certify as follows:

1. The net weight of the contents of the package.
2. The name, brand or trade-mark under which it is to be sold.
3. The name and principal address of the manufacturer or person responsible for the placing of the commodity upon the market.
4. The minimum per centum of each of the following constituents which may be contained therein:
    - (*a*) Nitrogen.
    - (*b*) Available phosphoric acid, except that in cases of undissolved bone, basic slag phosphate, wood ashes, untreated phosphate rock, garbage tankage and pulverized natural manures, the minimum per centum of total phosphoric acid may be substituted therefor.

(*c*) Potash soluble in distilled water.

(*d*) In the case of ground limestones, marls, mussel shells, and other calcium and magnesium carbonates used for agricultural purposes, the minimum per centum of carbonate expressed as calcium oxide and magnesium oxide.

(*e*) In the case of burned or hydrated limes, the minimum per centum of calcium oxide and magnesium oxide.

(*f*) In the case of other materials containing calcium and magnesium compounds, the minimum per centum of carbonate present, expressed as calcium oxide and magnesium oxide.

If any commercial fertilizer, or material to be used as a fertilizer, be sold, offered or exposed for sale in bulk such printed statement shall accompany every lot and parcel so sold, offered or exposed for sale.

That portion of the statement required by this section, relating to the chemical composition of commercial fertilizer or material to be used as a fertilizer, shall be known as the guaranteed analysis.

*Violations.* It shall be a violation of the provisions of this article if the statement required by the last preceding section shall be false in regard to the net weight of the contents of the package sold, offered or exposed for sale, or in the name, brand or trade-mark under which the fertilizer is sold, or in the name and address of the manufacturer or person responsible for placing the commodity upon the markets. It shall also be a violation of the provisions of this article if any commercial fertilizer or material to be used as a fertilizer shall contain a smaller percentage of nitrogen, phosphoric acid, potash, calcium oxide or magnesium oxide than is certified in said statement to be contained therein.

## 8. The Manufacture of Superphosphate

Superphosphate is made by mixing concentrated sulfuric acid with ground phosphate rock. Approximately equal parts by weight of the two materials are mixed together. They react chemically, the acid being largely destroyed, and the phosphorus in the rock phosphate changed from an unavailable to an available form. The chemical reaction may be expressed as follows:

$$\mathrm{Ca_3(PO_4)_2} + \mathrm{2H_2SO_4} = \mathrm{CaH_4(PO_4)_2} + \mathrm{2CaSO_4}$$

$$\binom{\text{Tricalcium}}{\text{phosphate}} + \binom{\text{Sulfuric}}{\text{Acid}} = \binom{\text{Monocalcium}}{\text{phosphate}} + \binom{\text{Calcium}}{\text{sulfate}}$$

Both the phosphate rock and the commercial sulfuric acid used contain impurities which carry over into the superphosphate. The calcium sulfate, often termed gypsum or land plaster, contains water of hydration. Some of the phosphoric acid may change back to the dicalcium form ($Ca_2H_2(PO_4)_2$); some normally remains in an unavailable form, combined with iron or aluminum in the superphosphate. There is usually some "free acid" in the form of $H_3PO_4$ in superphosphate. For all practical purposes the standard 20 per cent grade of superphosphate contains approximately 50 per cent of gypsum and 20 per cent of available phosphoric acid, most of which is water-soluble. The more concentrated grades of superphosphate contain relatively less gypsum, and the double superphosphate has had all the gypsum replaced by calcium phosphate.

Ammoniated superphosphate is manufactured by incorporating a small amount of liquid ammonia with superphosphate. The product contains about 2 per cent nitrogen in addition to 18 per cent available phosphoric acid.

## 9. Experimental Results

Literally thousands of field experiments have been conducted with different fertilizers on various soils and crops. Some have been continued over periods of twenty to more than fifty years. The application of results is largely restricted to the soil and climatic conditions under which the tests were made. The systems of fertilization outlined in this and other chapters have been based, to a large extent, on the results of experimental work. It is suggested that those interested in such results, farmers as well as students, secure and study available publications in which the results of experimental work done with fertilizers, especially in one's home state, are recorded.

## COMMUNITY STUDIES

1. Visit a local fertilizer dealer. Ascertain: (1) the grades of fertilizer used most extensively in the community; (2) the current prices of mixed fertilizers and fertilizer materials. (3) Make a copy of the guaranteed analysis appearing on the bag or on a tag attached thereto. (4) If possible, secure samples of the different fertilizers.

2. Visit several farms where fertilizers are used. Determine: (1) the analysis of fertilizer used; (2) the rate of application; (3) the method of application.

3. Examine the fertilizer attachment of a small-grain drill or a corn, potato, or cotton planter. Has provision been made to prevent the fertilizer from coming in contact with the seed?

4. Interview any local farmer who home-mixes his fertilizer. Secure his opinion as to the advantages of home-mixing. Secure from him the formula or formulas that he uses.

5. Study the guaranteed analysis secured from the local fertilizer dealer and state in simple terms the composition of each fertilizer. Determine which are in the high-analysis and which in the low-analysis group.

6. Examine each sample of fertilizer secured, and determine so far as possible the ingredients which it contains.

## PROBLEMS

1. A 5–10–5 fertilizer contains what percentage of nitrogen? What percentage of phosphorus? What percentage of potassium?

2. How many pounds of nitrogen, of phosphoric acid, and of potash are there in a ton of a 4–12–4 fertilizer?

3. What is the bone phosphate of lime (BPL) equivalent of the phosphoric acid in a 5–10–5 fertilizer? The sulfate of potash equivalent of the potash?

4. How many pounds of nitrate of soda, superphosphate (16 per cent phosphoric acid), sulfate of potash, and filler would it require for a ton of a 2–8–2 mixture? How many pounds without the filler would be required to equal a 400-pound application of a 2–8–2 mixture?

5. How many pounds of animal tankage, superphosphate (14 per cent phosphoric acid), kainit, and filler would be required for a ton of a 5–10–5 mixture or its equivalent?

6. Assume that you have a 5-acre patch of potatoes to fertilize. The application is to be equivalent to 1000 pounds to the acre of a 4–12–4 mixture. How much sulfate of ammonia, 16 per cent superphosphate and muriate of potash would you have to buy for the home-mixing of the fertilizer necessary for the 5 acres?

7. What would be the percentage in saving in buying a 10–20–10 analysis of mixed fertilizer at $55 a ton instead of a 5–10–5 analysis at $32.50 a ton?

8. If cyanamid is applied at the rate of 100 pounds to the acre every three years, how many years would be required for the cyanamid to reduce the acidity as much as a one-ton application of ground limestone? (Refer to Table XXXI.)

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# CHAPTER VIII

## LEGUMING AND GREEN MANURING

For a permanent and profitable system of fertilization the nitrogen needs of the crop must be supplied economically, and the organic-matter content of the soil conserved efficiently. On livestock farms, farm manure is a valuable asset in meeting these two essentials. On vegetable farms, and to some extent on fruit farms as well, nitrogenous fertilizer materials, such as nitrate of soda, may be used profitably as a source of nitrogen. However, catch crops and cover crops should be grown and returned to the soil as green manure in both

FIG. 152. A FIELD OF ALFALFA.

Irrespective of the type of general farming, legumes, either as regular crops in the rotation or as catch crops or cover crops, furnish nitrogen economically and organic matter efficiently.

garden and orchard, in order that the organic-matter supply may be replenished adequately. On grain and hay farms, where little livestock is kept, the nitrogen must be secured largely from the atmosphere through the growing of legume crops. Organic matter may be replenished not only by the return to the soil of the stubble of the crops, but also by the return of crop residues, such as cornstalks and straw, of good sods, and, under special conditions, of green-manure crops. Irrespective of the type of general farming, legumes, either as regular crops in the rotation or as catch crops or cover crops, furnish nitrogen economically and organic matter efficiently.

**Operations:**

1. Leguming land.
2. Securing the maximum growth of legumes.
3. Utilizing legumes to best advantage.
4. Growing green-manure crops and cover crops.
5. Utilizing crop residues.
6. Maintaining good sods.

### 1. Leguming Land

The practice of utilizing legumes as a source of nitrogen without returning them as green manure has been termed *leguming land.* It means the frequent growing of legumes in the rotation in order that available nitrogen may be secured from the inexhaustible supply of the atmosphere. The practical value of legumes used in this way is not yet fully appreciated, and there is still a widespread belief that for soil improvement a legume must be plowed down as green manure. The practice of leguming land should be classed with those of fertilizing, manuring, and green manuring. Until this direct value of legumes is fully appreciated, these crops will not be used most effectively in the maintenance or the improvement of soils.

On the average farm more legumes can be grown to advantage. By utilizing the nitrogen of the air they lessen the need for this expensive plant-food in fertilizers, thereby reducing materially the fertilizer bill. They are rich in protein, and when they are used as roughage in the feeding of livestock a concentrate lower in protein can be used, resulting in a reduction in the feed bill. The legumes more commonly used as roughage, such as alfalfa and clover, have a high lime and phosphorus content; and, when fed to young stock, produce bone of good quality.[1] From the standpoint both of fertilizer and of feed economy, legumes should be grown frequently in the rotation.

FIG. 153. ALSIKE CLOVER.

*Leguming land* means the frequent growing of legumes in the rotation in order that available nitrogen may be secured from the inexhaustible supply of the atmosphere.

Legumes take nitrogen from the air by means of bacteria. These bacteria penetrate the root hairs and multiply in the roots. As they multiply, enlargements form on the roots which are called *tubercles* or *nodules*. Their energy and most of their food are supplied by the plant sap. They utilize nitrogen of the air which circulates through the soil and for this reason are called *nitrogen-gathering* or *nitrogen-fixing bacteria*. Unless these nodules develop, legumes, like other plants, must secure their nitrogen from the soil. When nodules form in large numbers on the roots of legumes in nitrogen-deficient soils, even more nitrogen is normally taken from the air than from the soil.

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[1] See "Dairy Cattle," by Yapp and Nevens, published by John Wiley & Sons, for feeding of dairy cattle.

To secure the maximum benefit from legumes, either return them to the soil as a green manure or feed them to livestock and return the manure to the land. Either method of disposition returns to the soil a considerable amount of both the nitrogen and the organic matter of the tops. If livestock is kept in sufficient numbers to consume the legumes, they can be used most advantageously as feed. Otherwise, on grain and hay farms, the legumes grown as regular crops in the rotation should be sold as cash crops, and only those grown as catch crops or cover crops should be plowed under. Frequently a second growth, as of clover, may be returned to the soil.

Legumes need not be returned to the soil to be of benefit to the crop which follows. Even when they are removed and sold from the farm, there is an increase in the available nitrogen of the soil. Under favorable conditions, this may amount to as much as 100 pounds of available nitrogen to the acre as a result of one year of alfalfa or clover. This beneficial effect may be observed on the second and third crop following a legume. A non-legume grown with a legume may make a more vigorous growth than one produced alone. If

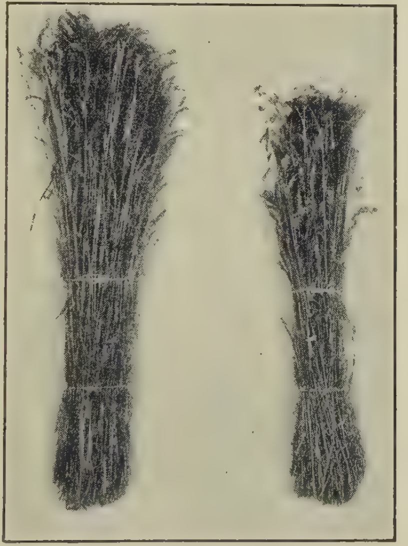

FIG. 154. WHEAT AFTER ALFALFA VS. WHEAT AFTER TIMOTHY.

Legumes need not be returned to the soil to be of benefit to the crop which follows. Even where removed and sold from the farm, there is an increase in the available nitrogen of the soil.

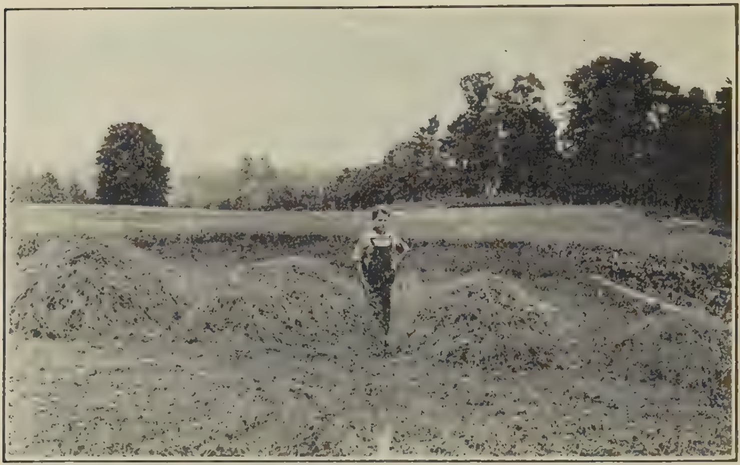

FIG. 155. LEFT TO RIGHT: TIMOTHY AFTER TIMOTHY AND CLOVER, SECOND-YEAR HAY; SAME, THIRD-YEAR HAY; TIMOTHY AFTER TIMOTHY, SECOND-YEAR HAY; SAME, THIRD-YEAR HAY.

The beneficial effect of legumes may be observed on the second and sometimes on the third crop following.

FIG. 156. A FIELD OF CLOVER AND TIMOTHY.

If timothy and clover are grown together, particularly on nitrogen-deficient soils, the timothy makes a better growth and is of a darker green color than if grown alone on the same soil.

timothy and clover are grown together, particularly on nitrogen-deficient soils, the timothy makes a better growth and is of a darker green color than if grown alone on the same soil.

Legumes may benefit the soil in other ways than by increasing the available nitrogen. They are deep-rooted crops, and when grown on heavy soils they may materially benefit the drainage, as the roots decay and leave openings through the subsoil. They draw more heavily on the subsoil for the mineral plant foods than do the shallower-rooted crops. Consequently, when the legumes are returned either as green manure or as farm manure, these minerals are returned to the surface soil. In this way a transfer of mineral plant-food from subsoil to surface soil is brought about.

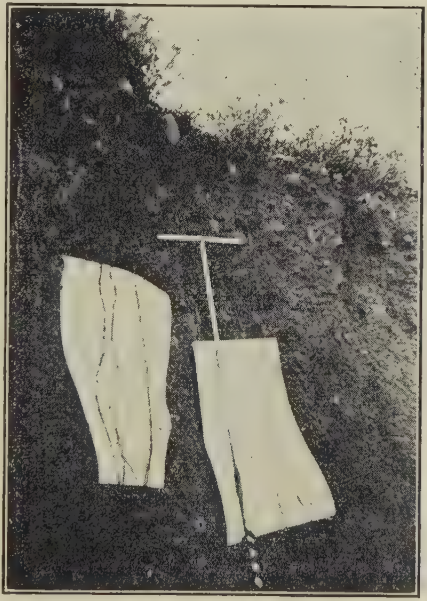

FIG. 157. ALFALFA ROOTS.

Legumes are deep-rooted crops and benefit the soil by transferring mineral plant-food from the subsoil to the surface soil.

Still another benefit of legumes is not generally appreciated. It is their value in replenishing the organic-matter supply of the soil. By furnishing available nitrogen to the crop following, increased growth is secured, which means more organic matter in the root and stubble; and when the crop is utilized as feed or bedding for livestock, there is also an increase in the organic matter returned in the manure. Consequently, legumes not only supply available nitrogen for the other crops of the rotation, but, to some extent at least, replenish the supply of both minerals and organic matter in the surface soil. Plan to grow a soil-improving legume on land every few years.

The value of leguming land is clearly shown by the results secured in a number of experiments. At the Pennsylvania Experiment Station, the yield of corn, oats, wheat, and hay grown in a four-year rotation has been maintained over a period of fifty years without the application of a nitrogenous fertilizer, farm manure, or a green-manure crop. Red clover has been grown with timothy as the hay crop; and even though all the crops of the rotation have been removed from the land, the yields have remained practically constant over this long period of years where the mineral plant-food constituents were supplied. At the Ohio Experiment Station, the yield of wheat in a three-year potato, wheat, and clover rotation has been maintained over two fifteen-year periods at 36 bushels to the acre, by the use of superphosphate and muriate of potash. At the Cornell Experiment Station, New York, clover

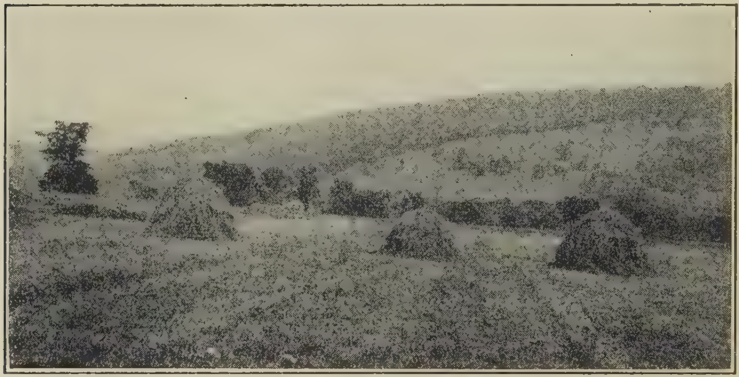

FIG. 158. CENTER—TIMOTHY AFTER TIMOTHY. RIGHT AND LEFT—TIMOTHY AFTER CLOVER AND TIMOTHY. (Agronomy Dept., N. Y. State Col. of Agr.)

The value of leguming land is clearly shown by the results secured in a number of experiments.

grown with timothy increased the yield of timothy hay the following year more than three times as much as did 100 pounds of nitrate of soda applied to second-year timothy which had been seeded without clover. The growing of white clover in permanent pastures has been found an economical source of nitrogen for the pasture herbage.[2]

## 2. SECURING THE MAXIMUM GROWTH OF LEGUMES

Success with legumes is an essential of good soil management. Not only must failure be prevented, but also a good growth must be secured. Otherwise, the legumes will not function efficiently either in the improvement of depleted soils or in the maintenance of productive ones. Under normal conditions, the larger the yield of a legume the greater will be its benefit to the crops that follow in the rotation.

FIG. 159. FIRST CUTTING ALFALFA.

Success with legumes is an essential of good soil management. Not only must failure be prevented, but also a good growth secured. Keep the land in sod for one-third, or, better still, one-half the time.

Legume crops utilize the nitrogen that becomes available in the soil during their growth. They draw on the air for additional nitrogen as it is needed. Consequently, where the yield is small, relatively less nitrogen is taken from the air. The nitrogen utilized by increase in yield above a certain point comes largely, if not entirely, from the air. Obviously, then, the efficiency with which a legume utilizes atmospheric nitrogen is dependent on the growth or yield of the crop. Likewise, its beneficial effect on heavy subsoils, its efficiency in transferring minerals from the subsoil to the surface, and its ability to replenish soil organic matter are dependent upon the amount of growth made.

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[2] See General Information at end of chapter for benefits of legumes.

FIG. 160. CLOVER SEEDING IN OATS.

For success with alfalfa and clover in a section where the winter is severe, use hardy northern-grown seed.

**Procedure:**

A. Plant hardy seed.
B. Inoculate.
C. Supply other essentials.

**A. Plant hardy seed.** Failure with red clover and alfalfa in the northern states is often due to the use of southern-grown seed. For success with these two legumes in a section where the winters are severe, use hardy northern-grown seed. As a result of a persistent demand for hardy seed of alfalfa and clover, a federal seed law requiring a guarantee of origin of the seed has been passed. Success with these two legumes requires, first of all, that properly adapted seed be used, and, as with legumes in general, that the seed be of good quality.[3]

**B. Inoculate.** Legumes not only fail to utilize atmospheric nitrogen, but normally make little growth unless they are inoculated. Many soils are naturally inoculated for certain of the legumes. The fact that a soil is inoculated for one legume does not necessarily mean that it is inoculated for all others. The more common legumes are classified in six groups, based on inoculation. Those within a group are inoculated by the same bacteria, but the different groups require different bacteria. Alfalfa and sweet clover are in the same group. Red and alsike clover are in another group. Consequently, a soil inoculated for sweet clover is not necessarily inoculated for either red or alsike clover.[4]

If a given legume has been successfully grown on a field, and the soil is well supplied with organic matter and maintained in a condition favorable for the growth of the legume, it will remain inoculated for this legume or any other of its group for a period of five to 10 years or longer. Farmed soils over much of the United States have been found to be rather universally inoculated for red clover and the other legumes of its group. On the other hand, soils are not commonly supplied with bacteria for alfalfa and sweet clover. Consequently,

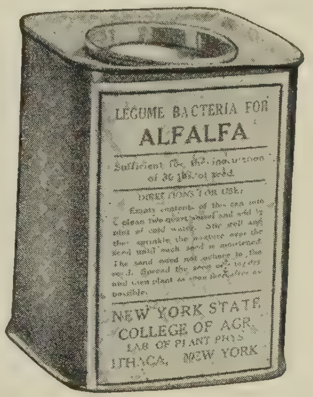

FIG. 161. ALFALFA INOCULATION.

Commercial cultures of the various legume bacteria can be used satisfactorily for inoculating seed.

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[3] See General Information at end of chapter for federal seed-staining law.

[4] See General Information at end of chapter for the six groups of legumes.

where grown for the first time on a piece of land, they should be inoculated. It is also essential for good yields on most soils to inoculate for vetch, soybeans, and Canada field peas the first time they are produced on a field. Under some conditions, inoculation may be of value even though the soil contains the desired bacteria; but if such a soil is in a good state of fertility, the benefit would not normally be sufficient to justify inoculation.

If inoculation is needed, it can be supplied by inoculating either the soil of the field or the seed before it is planted. To inoculate the field soil, secure soil known to be inoculated for the particular legume, scatter it over the surface of the field, and promptly harrow it into the topsoil. If the seed is to be inoculated, commercial cultures of the various legume bacteria can be used with satisfaction. Numerous brands of commercial inoculants are on the market. When using them, follow directions in detail. Soil secured from around the roots of thoroughly inoculated plants, or a commercial culture for a given legume, may be used for inoculating the seed of any of the legumes in the same group.[5]

**C. Supply other essentials.** Besides good seed and adequate inoculation, there are four other prime essentials for good yields of legumes. They are: (1) good drainage, though there are some legumes which will grow well in wet soils; (2) a well-prepared seed-bed; (3) lime; and (4) phosphorus. On the whole, legumes require even better drainage than nonlegumes since they are susceptible to heaving during the winter months, and this injury is less severe on well-drained soils. Where a soil is poorly drained, even the hardy strains of alfalfa and clover may be winter-killed as a result of heaving. Because of the smallness of the seed, such legumes as alfalfa and clover need an especially well-prepared seed-bed, and coverage should never be more than one-half inch. Though the lime requirement of legumes varies, those most extensively used for leguming land require liming if soils are acid. Almost without exception legumes are benefited by superphosphate or other phosphatic fertilizer. Where potassium is deficient, apply a potash material in addition to the superphosphate. A deficiency of lime, phosphoric acid, or potash will result in weaker root development, making the plants more susceptible to heaving. The heaving of both clover and alfalfa has been greatly reduced by the liberal application of superphosphate. The lack of full success with alfalfa and clover is most often due to one or more of the following causes: (1) winter-killing resulting from poor seed or inadequately drained soil; (2) lack of inoculation; (3) acid soil; (4) insufficient phosphoric acid or potash. The character and rate of seeding of the companion crop and improper seeding technique may be additional influencing factors. In dry climates sulfur may be needed as well as phosphoric acid or potash, particularly for alfalfa, and on very poor soils nitrogen may be helpful in establishing a seeding. One of the best sources of nitrogen for a legume seeding on depleted soil is farm manure. Determine the factors which influence the growth and yield of

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[5] See General Information at end of chapter for full directions for the inoculation of legumes.

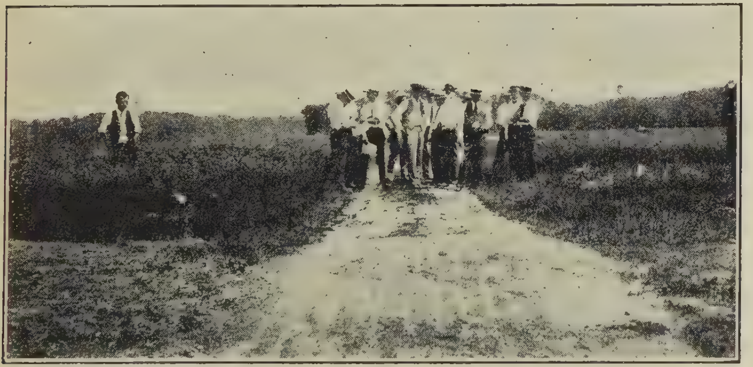

FIG. 162. ALFALFA. LIMED ON LEFT, UNLIMED ON RIGHT.

Though the lime requirement of legumes varies, those most extensively used for leguming land require liming if soils are acid.

legumes in the local community, and supply the essentials for successful legume production.

### 3. Utilizing Legumes to Best Advantage

The amount of nitrogen fixed by legumes varies with conditions. An inoculated legume, seeded in a nitrogen-free soil medium, is capable of securing from the air the nitrogen necessary for normal growth and final seed production. Grown under field conditions, a legume invariably secures part of its nitrogen from the soil. The richer the soil is in available nitrogen the less atmospheric nitrogen does a given growth

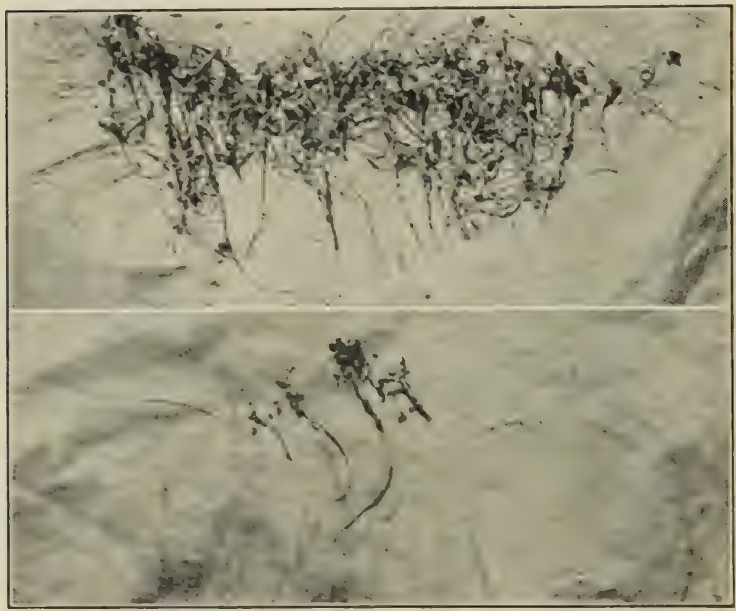

Fig. 163 Red Clover Plants Heaved from a Square Yard of Meadow.
Upper: Manure; Lower: Manure, Lime and Superphosphate.

A deficiency of lime, phosphoric acid, or potash will result in weaker root development, making the plants more susceptible to heaving.

of a legume utilize. Conversely, the poorer the soil the more efficiently is atmospheric nitrogen fixed, provided, of course, that the growth is not retarded. Other factors, such as the degree of inoculation, kind of legume, climatic conditions, amount of soil organic matter, and mineral plant-food supply, including lime, are all influential.

It is doubtful if the total nitrogen content of a productive soil can be increased materially by the growing of legume crops. It is not certain that an increase in nitrogen and organic matter would be secured, except in poor soil, even when the legume is returned as green manure or in the form of animal manures. Even so, the productivity of farmed soil has been maintained over a period of years by growing legumes and by supplying the necessary minerals as fertilizer. Leguming land should be looked upon as a means of securing a temporary supply of available nitrogen, and not as a practical way of permanently increasing the total nitrogen supply of the soil. However, the successful and frequent growing of legumes is recognized as an essential for the economic conservation of field soils.

To utilize legumes efficiently, then, grow them frequently in the rotation, and supply the essentials for good growth. Do not apply nitrogen as a fertilizer except where necessary to assure a stand, but force the crop to utilize the inexhaustible supply of the atmosphere. In systems of grain farming where little or no manure is returned, grow a legume such as clover once in three years. In general livestock farming, clover once in four years will suffice if the manure is well cared for. In intensive dairy farming where large amounts of concentrated feeds and some roughage are purchased, once in five years will prove adequate.

Some legumes are much more valuable than others in leguming land. Alfalfa and sweet clover have been found particularly valuable for this purpose. Red and alsike clover are also very effective in increasing the available nitrogen supply for the following crop, even though only the roots and stubble are returned. These four legumes seem to be in a class by themselves and can well be considered the most valuable of the legumes to be used as regular crops in the rotation. White clover is a most valuable legume for supplying nitrogen to permanent pastures, and the large growing Ladino variety is no doubt of great value in either pastures or hay meadows. Burr clover is an efficient soil-building legume for the South.

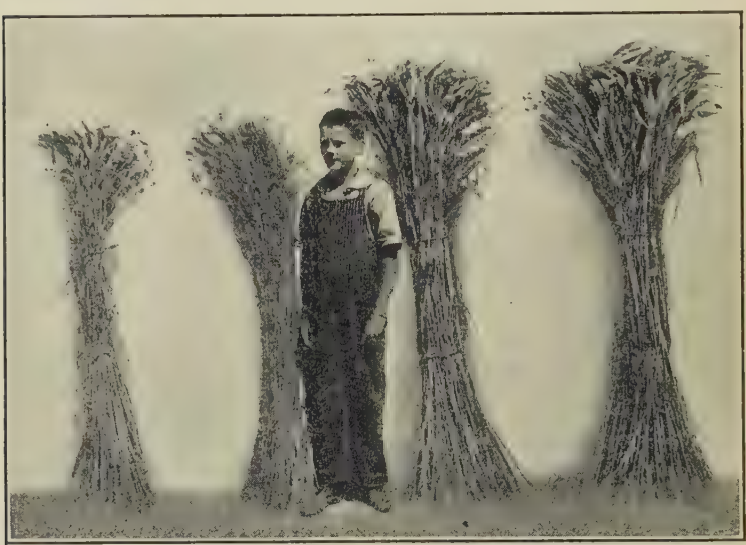

FIG. 164. LEFT TO RIGHT: RYE AFTER RYE; RYE AFTER SOYBEANS; RYE AFTER CLOVER; AND RYE AFTER ALFALFA.

Some legumes are much more valuable than others in leguming land.

Lespedeza is a poor land legume and may be used where one cannot afford the necessary lime to insure success with clover and alfalfa, but it is not sufficiently hardy for the northern states. Beans and peas of all kinds are far less effective than alfalfa and the clovers in leguming land. To be of material value, it is necessary that these less effective legumes be utilized as green manure. Less is known of the effectiveness of crimson clover and vetch, though in all probability they are superior to beans and peas. They are not, however, so extensively adapted to field-crop rotations as are red and alsike clover. Take into consideration, in choosing a legume, the effectiveness with which it utilizes atmospheric nitrogen.

Where a perennial legume, alfalfa, for example, is grown for several years, there is probably little accumulation of available nitrogen in the soil after the first year. Instead, the available nitrogen stored the first year is re-used by the second-year alfalfa. Each year the crop uses the available nitrogen secured the year before. Consequently, where the alfalfa hay is sold from the farm, little additional benefit is secured after the year of greatest growth. If left on the land until it largely runs out, the soil, in all probability, contains less available nitrogen for the following crop than it did at the end of the second year. To be used most efficiently as a source of available nitrogen for the other crops, alfalfa should be grown in a relatively short rotation.

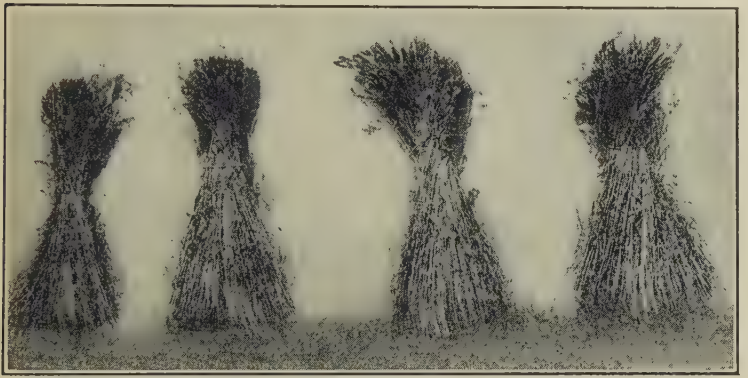

FIG. 165. LEFT TO RIGHT: WHEAT AFTER GRAIN; WHEAT AFTER ONE YEAR OF ALFALFA; WHEAT AFTER TWO YEARS OF ALFALFA; AND WHEAT AFTER THREE YEARS OF ALFALFA.

Where a perennial legume, alfalfa, for example, is grown for several years, there is probably little accumulation of available nitrogen in the soil after the first year.

### 4. GROWING GREEN-MANURE CROPS AND COVER CROPS

The growing of crops to be plowed under while still green has been found a practical means of replenishing soil organic matter on many farms. This practice is termed *green manuring.* Catch crops and cover crops are commonly used for this purpose, as they do not interfere with the regular crops of the rotation. They can be utilized to best advantage as green manure where the supply of farm manure is inadequate or the cost prohibitive.

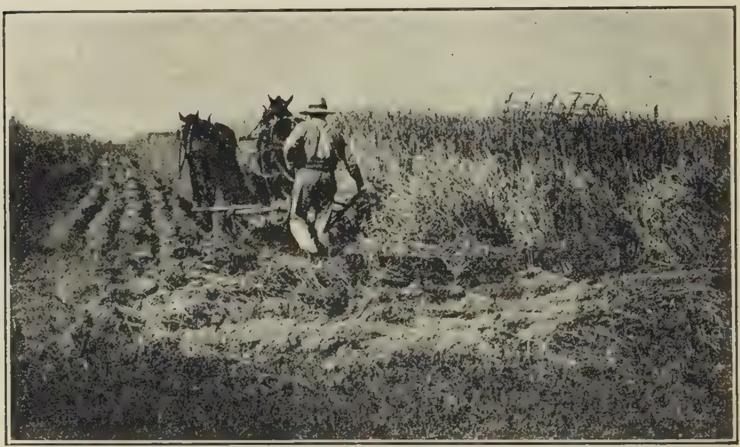

FIG. 166. PLOWING UNDER A GREEN CROP OF RYE.

The growing of crops to be plowed under while still green has been found a practical means of replenishing soil organic matter on many farms.

The organic-matter content of farmed soils must be kept at a fairly high level. This is not easily done. Even under the best systems of soil management it is difficult to increase the organic-matter content of a soil beyond a certain point without the purchase of organic material. Nevertheless, organic matter can be supplied in sufficient amounts, even though manure is not used, to keep the soil in a high state of productivity.

Every system of cropping and fertilization may be said to have its soil organic-matter equilibrium. Good soil management results in a high equilibrium; poor soil management in a low equilibrium.

In addition to improving the physical conditions of the soil, such as its tilth and water-holding capacity, organic matter as it decomposes furnishes plant-food in an available form. It is the storehouse of the nitrogen supply of the soil. In addition, it contains the various minerals used by plants. It also furnishes energy for soil organisms. These low forms of plant and animal life function most efficiently in soils well supplied with decomposable organic matter. They are themselves responsible for the decomposition, and they utilize certain of the products formed.

The decomposing process is exceedingly complicated. It normally consists of three stages: (1) putrefaction, (2) ammonification, and (3) nitrification. Although plants are known to utilize some nitrogen from the intermediate stages of decomposition, in practical crop production we are most concerned with the last stage called *nitrification.* The organisms responsible for producing this change are known as *nitrifying bacteria,* and the product formed is *nitrate nitrogen.*[6] This is a soluble and readily usable form of nitrogen. In the process of decomposition the mineral elements in the organic matter, as well as the nitrogen, become available. It has been found also that mineral plant-food becomes available more rapidly from the soil grains as the supply of decomposing organic matter is increased. Organic matter, then, may be considered an absolute essential of a productive soil, and maintaining it at a relatively high level is an essential for effective soil conservation.

Green-manure crops, particularly when grown as cover crops, conserve soil nitrates. Nitrogen is constantly becoming available, except when the soil is frozen, and, unless utilized by growing plants, leaches away in the form of nitrates. Cover crops also make use of the mineral plant-food that becomes available, and, where returned as green manure, these minerals go back to the soil and become rapidly available to the following crops. Cover crops are also of value in preventing both water and wind erosion. In general, it is a good practice to keep a crop of some kind on the land at all times, and particularly throughout the full growing season.

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[6] See page 31 for information on bacteria and other soil organisms.

**Procedure:**

A. Consider growing green-manure crops when conditions are favorable.
B. Select the crops to grow.
C. Grow properly.
D. Plow under at proper stage of growth.

**A. Consider growing green-manure crops when conditions are favorable.** Green-manure crops have been found particularly well adapted to market gardens and truck farms. Owing to the diminishing supply of manure available from the cities, vegetable producers have been forced to depend more and more on green manures for organic matter. The practice of green manuring fits well into vegetable production, since many vegetables are short-season crops and thus permit the growing of a green-manure crop the same year. Also, because of the richness of garden soils, green-manure crops grow more rapidly and luxuriantly on them than on ordinary soils. The heavy applications of fertilizer commonly made for vegetables make it most essential that a cover crop be grown to utilize and conserve the residual effect of the fertilization. Except where manure is used in large amounts, grow green-manure crops if vegetables are produced for either market or home consumption.

Cover crops are an essential part of efficient soil management for tilled orchards. Plant in the summer or early fall, and plow down as green manure to replenish the organic matter of the surface soil. Such crops reduce the nitrate and water supply of the soil at the season when a reduction is desirable for the proper ripening and coloring of the fruit. Cover crops, returned as green manure, can be used to good advantage in vineyards.

Green manuring in connection with field-crop production has its limitations. In the Cotton Belt, with its long growing season, green manuring is extensively practiced, and is an essential in the successful permanent production of cotton. However, in the northern states, with the shorter growing season, there is less opportunity to utilize green-manure crops in the regular field-crop rotations. It has been found economically unsound to devote a full growing season to a green-manure crop. On the strictly grain farms catch crops may be grown under favorable conditions, and occasionally a second growth of a crop such as clover, may be plowed under as green manure. In livestock farming green manuring is impractical, for the crops can be utilized to better advantage as feed and the organic matter replenished with farm manure and the plowing under of sods. In arid and semi-arid sections, on account of the heavy drain on the soil-moisture supply, the practice of green manuring is also limited in its application. Not only does the growing crop draw on the soil moisture, but also the decomposition of the organic matter within the soil requires water and becomes an additional drain on the limited supply of the soil.

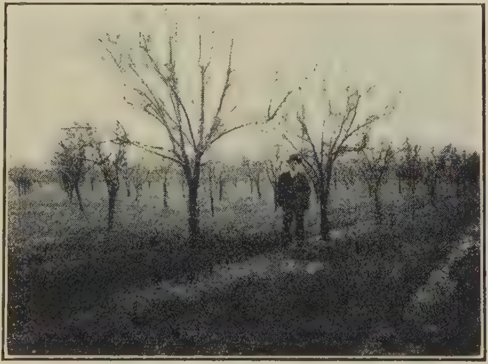

Fig. 167. A Cover Crop in an Orchard.

Cover crops are an essential part of efficient soil management for tilled orchards.

**B. Select the crops to grow.** Crops grown for green manure fall into two groups: the legumes, and the non-legumes. Of the two, the legumes are the more valuable since they can utilize atmospheric nitrogen. In the green state they are very succulent, and generally have a higher moisture content than the non-legumes. As a result, they decompose very rapidly in the soil, and drain less heavily than the non-legumes on the soil-moisture supply. This is particularly true of sweet clover. The legumes are also more efficient than the non-legumes in replenishing the soil organic matter. On poor soils, the legumes will grow more vigorously than the non-legumes, provided the essentials, other than nitrogen, are supplied. Of the legumes, sweet clover, winter vetch, crimson clover, and cowpeas are especially valuable.

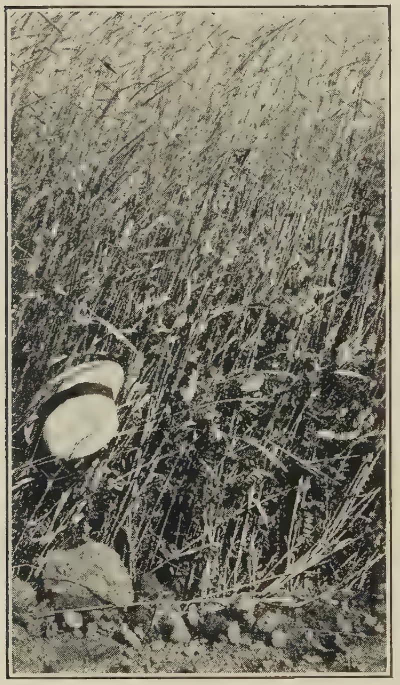

Fig. 168. Rye and Vetch.

Sometimes a combination of a legume and a non-legume can be used to advantage as a green-manure crop. Rye and winter vetch are frequently grown together.

Non-legumes can be used to best advantage on very rich soils, where the soil is heavily manured, or where liberally fertilized with a nitrogenous fertilizer. Under either of these conditions nitrogen becomes available from the soil; and the non-legume utilizes it for growth, thus conserving it by producing a new supply of organic matter. Of the non-legumes, rye is most extensively used as green manure. There are three possible advantages of the non-legumes: (1) they make more rapid growth; (2) the seed is cheaper; and (3) they are less subject to winter-killing. Where conditions are favorable, seed legumes in preference to non-legumes as green-manure crops. On rich soil, particularly where grown as a winter crop, consider using a hardy non-legume such as rye.[7]

Sometimes a combination of a legume and a non-legume can be used to advantage as a green-manure crop. Rye and winter vetch are frequently grown together. The rye supports the vetch, and the vetch utilizes atmospheric nitrogen. In general, the non-legume green-manure crops conserve soil nitrogen and organic matter; the legumes under favorable conditions increase the available nitrogen supply, and may actually increase the total soil supply of both nitrogen and organic matter.

**C. Grow properly.** There are three common ways of producing green manure: (1) as cover crops, (2) as catch crops, and (3) as second growth of harvested crops.

Cover crops are generally seeded in the fall, and as they occupy the land during the winter months they are frequently called winter cover crops. Rye, winter oats, wheat, vetch, sweet clover, and crimson clover are some of the crops used for this purpose.[8] The growing of winter cover crops has been found practical in tilled orchards and on vegetable farms. In field-crop production, their use should be restricted to sections where the growing season is long and the winters mild.

Catch crops can be seeded either after the regular crop has been harvested or at some time during its growth. The former practice is restricted to sections with a long growing season. Here, cowpeas, soybeans, or some other rapid-growing crop can be produced after early vegetables. The crop may be turned under as green manure in the fall, and a winter

[7] See General Information for experimental results with legumes and non-legumes as green manures.

[8] See General Information for list of cover crops with rates of seeding.

cover crop planted. The practice of seeding a green-manure crop with a regular rotation crop can be employed where the growing season is long. Any one of several crops may be seeded in corn, cotton, or other cultivated crop at the time of the last cultivation. Narrow, three- or four-hoe drills are used in some sections for seeding catch crops between the rows of corn and cotton. In grain-crop rotations sweet clover may be seeded on wheat during the winter or early spring. After the wheat is cut, permit the clover to grow until plowed under in the early spring. In the latter case it would be a cover crop as well as a catch crop.

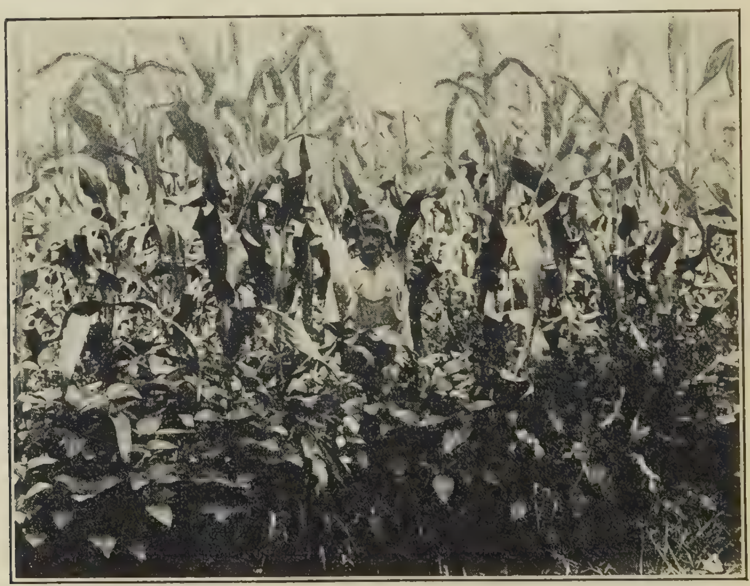

FIG. 169. COWPEAS IN CORN. (Agronomy Dept., Ill. Agr. Exp. Sta.)

The practice of seeding a green-manure crop with a regular rotation crop can be employed where the growing season is long.

The second growth of clover, or clover and timothy, may be used for green manure. On livestock farms either cut and feed or pasture the second growth of hay. In grain farming, on the other hand, plow it under as a green manure, except on soil very rich in organic matter.

**D. Plow under at proper stage of growth.** Green-manure crops should be plowed under when the plants are succulent. In this state they decompose rapidly in the soil, supplying available plant-food for the following crop. When permitted to approach maturity they draw heavily on the soil-moisture supply during the later stages of growth, and when plowed under make additional demand on the soil moisture in order to secure sufficient water for decomposition. Where the green-manure crop is plowed under in the fall and the land is not to be seeded until spring, permit it to reach a more mature stage. Let a legume crop grow larger than a non-legume before plowing under, since the additional growth will result in the legume's fixing additional atmospheric nitrogen, much of which will become available for the following crop.

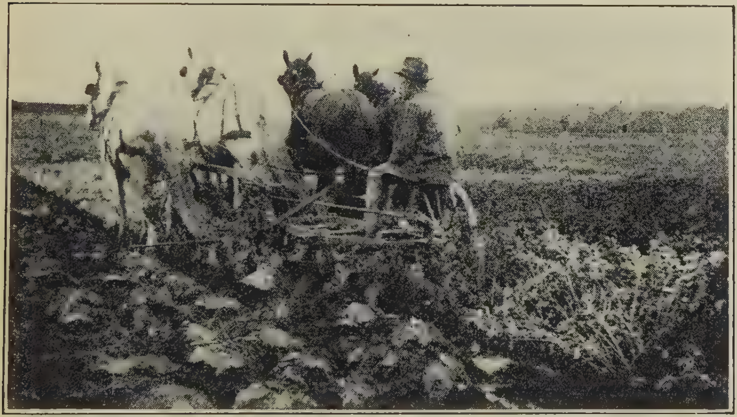

FIG. 170. PLOWING UNDER SWEET CLOVER. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Green-manure crops should be plowed under when the plants are succulent. In this state they decompose rapidly in the soil, supplying available plant-food for the following crop.

When plowed under in the succulent state, fully 50 per cent of the green manure decomposes the first year. For a short period after a heavy growth of a green-manure crop is plowed under, seed germination may be injured. The application of lime to be plowed under with the green crop may hasten decomposition, and reduce any injury to the germination of the seed of the following crop. For non-legume green-manure crops, an application of a nitrogenous fertilizer material just before plowing under will greatly hasten decomposition. By plowing under in the succulent state fully two weeks prior to the seeding of the following crop, good results will invariably be secured the first year. It is always desirable to follow a green-manure crop with a non-legume, preferably a cultivated one.

## 5. Utilizing Crop Residues

It is necessary on many farms to replenish the organic-matter supply of the soil largely through the return of crop residues. Even with the return of residues, soil organic matter cannot be maintained at a desirable level if grain, cotton, or other soil-depleting crops are grown exclusively. In the South, one should utilize cotton stalks in this way. In the grain sections, where cornstalks and straw are often produced in excess of the needs of the livestock kept, return them to the land and plow under, in preference to burning them. On vegetable farms, plow the residues under directly, or place in piles until partially rotted before returning to the land. The latter method of handling is called *composting*. Materials that hasten the decomposition of compost may be purchased. When compost is made of straw or similar dry residue, large quantities of water must be applied to it. The resulting material is known as *artificial manure*. The labor cost is prohibitive except in very intensive vegetable production.[9]

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[9] See General Information at end of chapter for directions for making artificial manure, and at end of Chapter XI for making compost.

Where residues decompose on the surface there is a rapid loss of organic matter. The decomposition process should take place in the soil. Unfortunately, when residues of mature crops are plowed under, they cause a temporary reduction in the soil nitrates and thus compete with the crop for nitrogen. To avoid this temporary injurious effect, plow the residues under in the fall on land which is to be used for a spring crop.

FIG. 171. CORNSTALKS LEFT OVER WINTER TO BE PLOWED UNDER IN THE SPRING.

It is necessary on many farms to replenish the organic-matter supply of the soil largely through the return of crop residues.

Occasionally straw and stover bring a price high enough on the market to justify selling them. In some communities the practice of burning certain of the crop residues can be justified on the ground of controlling plant diseases and insect pests. So far as possible, plow all residues under unless they can be utilized as feed or bedding for livestock, in which event they will be returned in the farm manure.

### 6. Maintaining Good Sods, or Practicing Grassland Farming

Considerable amounts of organic matter are retained in the roots and stubble of crops. This is particularly true of meadow and pasture sods. The grass crops, such as timothy and bluegrass, have fibrous roots which permeate the surface soil and materially improve its physical condition. This beneficial effect of sod is always apparent in the plowing of sod land. The small grass roots decompose rapidly when the sod is plowed under, and supply available plant-food, especially nitrogen, to the following crop. This is the reason that corn, with its high-nitrogen requirement, does so well on sod land.

Since sod reduces soil erosion to a minimum, it reduces the loss of surface soil and consequently of soil organic matter. Where clover is combined with grass in either meadow or pasture, nitrogen is secured from the atmosphere. In addition to the nitrogen-gathering bacteria of the legumes, another group of soil bacteria is capable of utilizing atmospheric nitrogen. They are known as *independent bacteria,* and are particularly active in soils that are well supplied with organic matter. *Azotobacter* and *Clostridium* are two of the most important of the independent bacteria. Pastures, and meadows as well, where the hay is fed and the manure returned, gain rather than lose in nitrogen and organic matter, provided that a good vigorous sod is maintained. This appears particularly true when the sod is composed of a mixture of grass and clover. Under favorable conditions, independent bacteria may fix as much as 40 pounds of nitrogen to the acre a year.

In practice, sods are too frequently permitted to "run out" before they are plowed down. The practice of leaving land in timothy for a long period of years has not been conducive to soil improvement. As a result, timothy is considered a soil-exhausting crop. However, when it is grown for one or two years, and a heavy sod plowed down, it is in reality a soil-improving crop. Especially is this true if clover is seeded with it, or if it is top-dressed with manure or a nitrogenous fertilizer. In the same way, land left in permanent pasture until the sod is thin may actually become depleted; but if a heavy sod is maintained by proper soil treatment and the introduction of clover, the soil will become more productive from year to year.

A practical field-crop rotation conducive to the maintenance of soil organic matter must provide for at least one sod crop. Keep the land in sod for one-third, or, better still, one-half the time. A legume sod or a mixed grass and legume sod is preferable to one composed of grass alone. Where the sod is composed largely of grass, top-dress it with manure or a nitrogenous fertilizer. Plow down all sods before they become thin, and, in general, follow with a cultivated crop such as corn or potatoes.

FIG. 172. PLOWING UNDER SOD.

A practical field-crop rotation conducive to the maintenance of soil organic matter must provide for at least one sod crop.

For soil conservation sod crops are in a class by themselves. They not only include the true grasses but many of the better soil-improving legumes as well. The terms *grassland farming* and *grassland agriculture* have been applied to cropping systems in which sod crops occupy a large proportion of the cropped and grazed land. Soil-depleting crops are grown only to the extent required for a practical rotation system. In extreme cases, sod crops may be grown to the exclusion of all others, but this type of grassland farming can seldom be justified.

The extent to which farm land can be kept in grass depends largely on the amount and kind of livestock. Although more sod crops should be grown in the grain- and cotton-producing sections, an adequate amount of sod requires farm animals as a means of utilizing efficiently the grass and legume roughage. The amount of hay which can be disposed of as a cash crop will always be limited. In dairy sections the use of grass and legumes for silage is receiving much consideration.

Sod as a means of soil conservation is of value not only because of its efficiency in erosion control, but also because it makes possible the maintenance of soil organic-matter at a high level and is an economic source of nitrogen. When sod crops are grown and fed to livestock and supplementary grain feed is purchased, the soil will automatically be conserved provided, of course, the sod is not permitted to become poor in quality. The establishment of perennial legumes in both hay meadows and permanent pastures is essential for maximum efficiency. Soil conservation is dependent largely on the proportion of land in sod, and the quality and disposition made of the sod crops.

## GENERAL INFORMATION

### 1. Benefits of Legumes

The beneficial effect of legumes on the succeeding crops has been determined in a number of experiments. At the Cornell Experiment Station red clover grown in small areas has been compared with rye in its effect on the four following crops. Both the clover and the rye were harvested and only the roots and stubble returned. The yields of the four crops are given in Table XXXIV.

The comparative effect of alfalfa and timothy has also been determined under field conditions. The two crops had been grown separately for hay over a period of eight years. Some alsike clover volunteered with the timothy. At the end of the eight-year period, the alfalfa sod had become thin and contained considerable amounts of weeds and grass. Even so, distinctly larger yields of grain crops were secured for three consecutive years after the alfalfa than after the timothy, as shown in Table XXXV.

TABLE XXXIV

Yield of Crops Following Red Clover and Rye, Respectively

| | Acre Yields | | | |
|---|---|---|---|---|
| | First Crop, Oats, Bu. | Second Crop, Wheat, Bu. | Third Crop, Corn Fodder, Tons | Fourth Crop, Wheat, Bu. |
| After red clover | 98 | 37 | 3.7 | 35 |
| After rye...... | 53 | 24 | 3.5 | 32 |

TABLE XXXV

Yield of Grain Crops after Alfalfa and Timothy Sod, Respectively

| | Acre Yields | | |
|---|---|---|---|
| | Bu. Corn | Bu. Oats | Bu. Wheat |
| After alfalfa sod................. | 80 | 74 | 40 |
| After timothy sod................ | 54 | 63 | 36 |

The comparative effectiveness of different legumes in benefiting the crops following is shown in Table XXXVI. These results were also secured at the Cornell Station. As in the other tests the legumes were removed and only the roots and stubble returned. Lime, phosphoric acid, and potash were supplied to make conditions favorable for the legumes.

TABLE XXXVI

The Comparative Effectiveness of the Different Legumes

| Kind of Legume | Total Acre Yield, Tons of Grain and Straw Combined over Three-year Period, Including 1 Barley and 2 Rye Crops |
|---|---|
| Alfalfa | 8.75 |
| Sweet clover | 8.57 |
| Red and alsike clover mixed | 8.21 |
| Alsike clover | 8.08 |
| Red clover | 7.95 |
| Soybeans | 4.44 |
| Field beans | 4.25 |
| Non-legume (oats or rye) | 2.68 |

The value of red clover in a corn rotation is clearly shown by the results secured at the Illinois Experiment Station. Corn has been grown continuously since 1879, in comparison with corn grown in rotation. A definite three-year rotation was established in 1888, and since 1904 the experiment has been continued both with and without fertilizer. The average yields of corn for the period 1904 to 1925, inclusive, both with and without fertilizer, are given in Table XXXVII.

TABLE XXXVII

Average Corn Yields, Morrow Plats, Illinois Experiment Station

| Continuous Corn | | Three-Year Rotation | |
|---|---|---|---|
| No Fertilizer | Lime, Manure, and Phosphorus | No Fertilizer | Lime, Manure, and Phosphorus |
| 24 bu. | 52 bu. | 35 bu. | 69 bu. |

## 2. Federal Seed Law

This law requires the staining of red clover and alfalfa seed imported into the United States. The staining is done either by the customs authorities at the port of shipment or by those at the port of entry into the United States. The staining requirements are as follows:

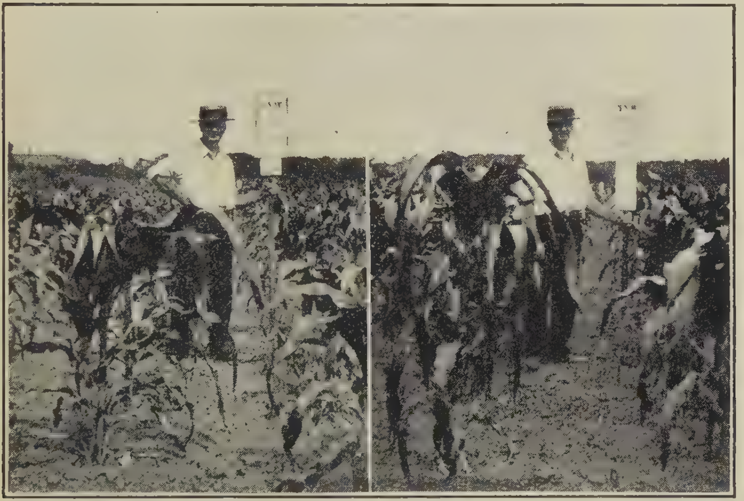

Fig. 173. Corn on Morrow Plats at the Illinois Experiment Station. Left: Corn after Corn; Right: Corn after Red Clover. (Agronomy Dept., Ill. Agr. Exp. Sta.)

The value of red clover in a corn rotation is clearly shown by the results secured at the Illinois Experiment Station.

(1) Seed known to be unadapted for general use in the United States, or the source of which is unknown, is stained red to the extent of 10 per cent of the kernels.

(2) Seed not definitely determined as unadapted for general use in the United States is stained green to the extent of 1 per cent of the kernels. Alfalfa seed from South America has 10 per cent stained orange-red.

(3) Seed produced in Canada is stained violet to the extent of 1 per cent of the kernels. It is adapted to general use in the United States.

(4) Seed of domestic origin must have a tag attached to each bag on which is recorded the location of its production.

## 3. Methods of Inoculation

**A. Commercial cultures.** Three types of commercial materials are available for the inoculation of the seed of legumes. They differ in the kind of medium used to carry the bacteria, and they may be classified as follows:

(1) Sand or soil cultures.
(2) Jelly cultures.
(3) Liquid cultures.

These commercial cultures are prepared in such a way that each contains the bacteria required for inoculating a specified legume or group of legumes. By sterilization, other organisms which might be injurious are destroyed. They are often designated as *pure cultures*. Any one of the three types may be used with entire satisfaction, provided that the material is fresh and the seed treated according to the directions furnished with the material. It is very important that the directions be followed in detail, and the seed planted within a few days after treatment. These commercial cultures are inexpensive and, in general, their use is preferable to other methods of inoculation.

**B. The glue method.** Another method of inoculating the seed is to secure soil from around the roots of inoculated legume plants belonging to the same group as the legume which is to be inoculated. Sift this soil, and partly dry without exposing to the direct sunlight. To make certain that a sufficient amount of the inoculated soil adheres to the seed, glue should be added to the water. Dissolve a pint of liquid glue or a pound of dry furniture glue in a gallon of water, and use this solution for moistening the seed. Moisten the seed to be inoculated with a pint to a quart of the solution to the bushel of seed. Milk may be used instead of glue and water, as it makes the seed sufficiently sticky. The addition of a small amount of starch or of sugar to supply nourishment for the bacteria, is often advised. Mix a quart or more of inoculated soil with each bushel of moistened seed. The inoculated seed should be spread out promptly on a canvas or a tight barn floor to dry. Do not expose to direct sunlight while drying. When thoroughly dry, re-bag until needed for seeding.

**C. Field inoculation.** Instead of treating the seed, the soil itself may be inoculated by the following method. Secure soil from the surface 6 inches of a field on which a legume of the desired group is growing. Make certain that there is a good development of tubercles on the roots. Apply this soil at the rate of several hundred pounds to the acre. If sifted, it may be applied with a lime distributor or the fertilizer attachment of a grain drill. If applied to the surface, harrow the field promptly to mix it with the topsoil. Owing to the labor involved, this method has largely been replaced by the use of commercial cultures.

In some communities it is a common practice to sow a small amount of alfalfa seed with a clover or clover-and-timothy seeding, as a means of inoculating the field for a future seeding of alfalfa or sweet clover. Where this is done, the alfalfa seed used should itself be inoculated by means of one of the methods suggested.

## 4. The Six Groups of Legumes

On the basis of inoculation, legumes are classified in six groups:

| | |
|---|---|
| Group 1 | Alfalfa<br>Sweet clover<br>Burr clover |

| | |
|---|---|
| Group 2 | Red clover<br>Alsike clover<br>White Dutch clover<br>Wild white clover<br>Crimson clover<br>Ladino clover |
| Group 3 | Canada field pea<br>Garden pea<br>Vetch |
| Group 4 | Cowpea<br>Peanut<br>Japan clover<br>Velvet beans<br>Lima beans |
| Group 5 | Soybean |
| Group 6 | Garden beans<br>and field beans |

Legumes within a group respond to the same inoculation, but they cannot be inoculated successfully with the bacteria of another group. There is evidence that nitrogen-fixing bacteria may gradually adapt themselves to other groups of legumes than the one on which they developed.

## 5. Crops Used as Green-Manure and Cover Crops

The more common green-manure crops and cover crops with rates of seeding are given in Table XXXVIII.

Burr clover and velvet beans are suited to warm climates only. Crimson clover and cowpeas require a moderately warm climate, whereas Canada peas, buckwheat, and timothy are adapted to the cooler sections of the country. Oats are commonly mixed with Canada peas in the proportion of 1 bushel of each, and the mixture seeded at the rate of 2 to 3 bushels to the acre. In the southern states, a mixture of 2 bushels of oats and ½ bushel of hairy vetch is frequently seeded in the fall as a winter cover crop to be plowed under in the spring as green manure or cut for hay. Where vetch is produced as a cover crop, rye is commonly mixed with it at the rate of 1 bushel of rye to ½ bushel of vetch, and the mixture seeded at the rate of 1½ to 2½ bushels to the acre.

### TABLE XXXVIII

### COVER CROPS AND GREEN-MANURE CROPS

| Crop | Character | Acre Rate of Seeding |
|---|---|---|
| Alfalfa | Legume—perennial | 15 to 20 lbs. |
| Alsike clover | Legume—perennial | 8 to 12 lbs. |
| Buckwheat | Non-legume—annual | 1 to 1½ bu. |
| Burr clover | Legume—annual | 15 to 20 lbs. |
| Canada field pea | Legume—annual | 30 to 60 lbs. |
| Cowpea | Legume—annual | 1½ to 2 bu. |
| Cowhorn turnips | Root crop—annual | 2½ to 5 lbs. |
| Crimson clover | Legume—perennial | 15 to 20 lbs. |
| Lespedeza | Legume—annual and perennial | 20 to 30 lbs. |
| Oats | Cereal—annual | 2 to 2½ bu. |
| Rape | Non-legume—annual | 10 to 20 lbs. |
| Red clover | Legume—biennial | 10 to 15 lbs. |
| Redtop | Grass—perennial | 10 to 12 lbs. |
| Rye | Cereal—annual | 1½ to 2 bu. |
| Soybeans | Legume—annual | 1 to 2 bu. |
| Sweet clover | Legume—biennial | 15 to 20 lbs. |
| Sweet clover (Hubam) | Legume—annual | 15 to 20 lbs. |
| Timothy | Grass—perennial | 10 to 12 lbs. |
| Velvet beans | Legume—perennial | 10 to 12 lbs. |
| Vetch (hairy) | Legume—biennial | 15 to 30 lbs. |
| Wheat | Cereal—annual | 1½ to 2 bu. |

## 6. COMPARATIVE VALUE OF LEGUMES AND NON-LEGUMES AS GREEN MANURES

A comparison of legumes and non-legumes as green-manure crops, in connection with continuous corn production, was made at the Rhode Island Experiment Station. The green-manure crops were seeded in the corn at the time of the last cultivation. The legume green manure consisted of crimson clover, mammoth red clover, or a mixture of several legumes. Rye was used for the non-legume green manure. The average corn yields for a period of nineteen years are given in Table XXXIX.

### TABLE XXXIX *

LEGUME COMPARED WITH NON-LEGUME AS GREEN-MANURE CROPS

(Total acre yield of corn in bushels)

| Period | Kind of Green-Manure Crop | | |
|---|---|---|---|
| | Legume | Rye | None |
| 1896 to 1899 | 46.3 | 40.7 | .... |
| 1900 to 1905 | 48.0 | 40.0 | 35.5 |
| 1906 to 1914 | 49.0 | 32.0 | 25.0 |
| Average | 47.8 | 37.6 | 30.3 |

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* R. I. Exp. Sta. Bul. 173.

At the New Jersey Experiment Station a similar experiment has been conducted, in which manure as well as commercial fertilizer has been applied for the corn. The annual fertilizer application equaled 500 pounds to the acre of a 5–10–10 mixture. Corn has been grown continuously with a mixture of legumes seeded at the last cultivation, in comparison with rye seeded at the same time. The average yield of

### TABLE XL

LEGUMES COMPARED WITH NON-LEGUMES AS GREEN MANURE

| Treatment in Addition | Legumes as Green Manure, Bu. Corn | Rye as Green Manure, Bu. Corn |
|---|---|---|
| Nothing | 36 | 23 |
| ½ ton manure | 40 | 29 |
| 1 ton manure | 37 | 30 |
| 2 tons manure | 38 | 28 |

corn for thirteen years is given in Table XL. Even where manure is applied and a fertilizer rich in nitrogen used in addition, the legume green manure has been far superior to the non-legume.

## 7. Artificial Manure

The rate of decomposition of organic material may be hastened by making the conditions favorable to the functioning of the bacteria. It has been found that nitrogen is not supplied rapidly enough by the decomposing organic matter to satisfy the needs of the bacteria. The addition of an available nitrogenous fertilizer material, such as nitrate of soda or sulfate of ammonia, hastens the rate of decomposition, especially of such low-protein materials as straw and weeds. By using a small amount of lime and superphosphate, the process may be speeded up even more, and the resulting manure will have a higher fertilizing value. Where desirable, the commercial material Adco may be used instead of limestone, superphosphate, and nitrate of soda. To make artificial manure proceed as follows:

For each ton of dry organic material, use 50 to 75 pounds of nitrate of soda or sulfate of ammonia, 100 pounds of superphosphate, and 50 to 100 pounds of ground limestone.

First distribute a layer of organic material about 12 inches thick. Then scatter the fertilizer and lime on it in amounts specified. Now sprinkle with water, using, by weight, three to four times as much water as organic material. Repeat the procedure by adding additional layers of organic material and fertilizer, and watering each time. The heap should be 6 to 10 feet high, the sides should be vertical, and the top left flat so that rain water will soak into the stack. Additional sprinkling should be given every few days to prevent excessive heating. Decomposition will be hastened by forking over the material occasionally and sprinkling during the process.

In warm weather, decomposition proceeds very rapidly, and within a few weeks the material is ready for use. About three tons of artificial manure will be secured for each ton of dry organic material used. The composition and fertilizing value will be similar to that of superphosphated animal manure.

## COMMUNITY STUDIES

1. List the legume crops grown locally in field-crop rotations.
2. Examine the roots of the different legumes and note the size and shape of the tubercles.
3. If heaving of alfalfa or clover plants is observed in a new seeding, determine if it may have been caused by an insufficient amount of lime or phosphoric acid.
4. Examine the roots of alfalfa plants from good and poor areas of a field and determine whether there is any correlation between the growth of alfalfa and the tubercle formation.
5. Determine what legumes it is necessary to inoculate in the community. What method of inoculation is commonly used?
6. What is the source of the alfalfa and red-clover seed used in the community?
7. Examine alfalfa or sweet-clover fields in the early spring and determine the cause of any winter-killing that is apparent.
8. List the green-manure crops grown in the community.
9. What cover crops are grown?
10. In what way are crop residues utilized on local farms?
11. How many years is land left in sod? Is the sod in good condition when it is plowed under?
12. What suggestions have you for the improvement of local practices relative to the economic maintenance of soil nitrogen and organic matter.

## PROBLEMS

1. Calculate the value of a red-clover crop on the four crops following on the basis of the Cornell Station results (Table XXXIV), when crops are valued as follows: oats 40 cents a bushel, wheat $1 a bushel, and corn fodder $8 a ton.
2. On the basis of the Illinois Station results (Table XXXVII), and with corn priced at 50 cents a bushel, what is the average fertilizer value over a twenty-two year period of clover on the following corn crop, both with and without treatment.
3. Calculate the average increase in the yield of corn following a legume green-manure crop, over that following rye, on the basis of the New Jersey Station results as given in Table XL.

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# CHAPTER IX

## MANAGING FIELD SOILS

For the profitable production of field crops, fertilizer economy is essential. Certain of the cash crops, particularly field-grown vegetables, will return a profit from liberal applications of mixed fertilizers, but the grain and hay crops do not offer a sufficient margin of profit to justify large fertilizer expenditures. For their economic production, nitrogen must be furnished largely by legumes or by farm manure. This necessitates that they be grown in a rotation with legumes, and that any additional nitrogen needed be furnished so far as possible by farm manure, green manure, or crop residues. Essential, then, to the profitable fertilization of field crops, is the establishment of an adequate rotation. The fertilizer

FIG. 174. CROP ROTATION ON THE PENNSYLVANIA STATE COLLEGE FARM.

Essential to the profitable fertilization of field crops is the establishment of an adequate rotation.

practice should take into consideration the rotation as well as the individual crops.

**Operations:**

1. Choosing the rotation.
2. Establishing the rotation.
3. Fertilizing the rotation.
4. Evaluating the soil-management program.

## 1. Choosing the Rotation

Grow field crops in a well-planned rotation. The continuous production on the same field of a single crop, other than sod, has been found unwise, and in the long run unprofitable. Cotton is still grown continuously in sections of the South, as is corn in parts of the Corn Belt, and wheat on certain western farms. Nevertheless, efficiency in production, including the profitable use of fertilizers and the replenishing of the organic-matter supply, necessitates that field crops be produced in rotations suited to both the soil and the climatic conditions.

**Procedure:**

A. Consider local rotation practices.
B. Plan the rotation.
C. Provide for emergency crops.

**A. Consider local rotation practices.** In choosing a rotation, give consideration to the cropping systems followed by the more successful farmers of the community. Their rotations have been tried out and found suited to the local conditions. It may be possible to improve such rotations, but seldom can they be successfully replaced by an entirely different cropping system.

**B. Plan the rotation.** A field-crop rotation should normally include three types of crops: a cultivated crop, a small-grain crop, and a hay crop. On livestock farms, where the permanent pasture area is inadequate, include in the rotation a pasture crop as a fourth type. Special cash crops, such as potatoes, beans, and sweet corn, can often be introduced to advantage, occupying part of the field devoted to one of the cultivated crops in the regular rotation.

In addition to being composed of crops adapted to the local soil, climatic, and market conditions, the rotation should make provisions for the following essentials of a good cropping system:

(1) Efficient utilization of labor throughout season.
(2) A legume soil-improving crop every three to five years.
(3) A sod crop, either legume, grass, or combination of the two.
(4) One or more cash crops.
(5) Feed and bedding for livestock.
(6) Substitute crops in case of failure of regular crops.
(7) Catch crops and cover crops where practical.[1]
(8) Soil conservation.

Corn, oats, and clover is a simple three-year grain and hay rotation. On rich Corn Belt land an additional corn crop is frequently included, and then the rotation consists of corn, corn, oats, and clover. The three-year rotation of potatoes, wheat, and clover is an excellent potato rotation. Other cultivated cash crops, such as beans, cabbage, and sweet corn, may be substituted for potatoes; and in sections where the growing season is short, oats or other spring grain may be substituted for wheat. On dairy farms, where a relatively large amount of hay is needed, the following four-year rotation is common in the northern states: silage corn the first year; a mixed spring grain such as barley or oats the second year; clover and timothy the third; and timothy the fourth. Where the soil is adapted to alfalfa, a five-year rotation of corn, mixed grains, and three years of alfalfa is excellent for the dairy farmer. For the Cotton Belt, a rotation of cotton with a legume green-manure crop the first year, corn the second, and oats and vetch or crimson clover hay the third year, followed with a legume soil-improving crop, has proved very effective.[2]

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[1] See General Information at end of chapter for list of advantages of rotating crops.

These standard rotations give the more common sequences of crops in field rotation systems. Local conditions necessarily influence the crop rotation or rotations best suited to a given farm. In determining the rotation for the individual farm, in addition to studying those followed by the better farmers of the community, keep in mind the essentials of an adequate rotation, consider the topography and size of the farm, make certain that the crops are suited to the local market conditions, and finally be sure that the rotation will make possible the efficient conservation of the soil.

FIG. 175. A FIELD OF BUCKWHEAT.

Often buckwheat is seeded in the late spring or early summer on land that could not be put in condition for spring grains.

**C. Provide for emergency crops.** Make provision for the introduction into the rotation of emergency crops to be substituted when regular crops fail, or when, because of labor shortage, unfavorable weather, or another emergency, the regular crop has not been planted in season. A spring grain, such as oats, barley, or spring wheat, is often produced when winter wheat fails; and in sections where buckwheat is grown, it is seeded in early summer on land that could not be put in condition for spring grains. Emergency hay crops include oats or a mixture of oats and peas, soybeans, millet, and Sudan grass. Although substitute crops are not ordinarily included in a statement of the rotation, nevertheless, in standard rotations provision has been made for their introduction.

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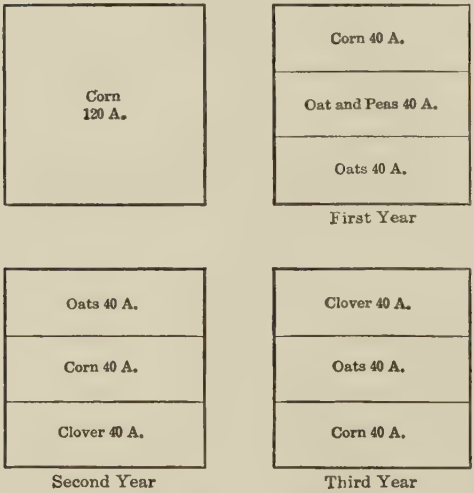
[2] See General Information at end of chapter for additional representative rotations.

### 2. Establishing the Rotation

In establishing a crop rotation, it is desirable to have the same number of approximately equal-sized fields as there are years in the rotation. This may necessitate a rearrangement of fields. Not infrequently, farms are divided into numerous small, irregularly shaped fields. Under such conditions, an adjustment of field arrangement is an essential factor of good farm management.



First Year

Second Year

Third Year

Fig. 176. Establishing a Three-Year Rotation of Corn, Oats, and Clover on a 120-Acre Farm on Which Only Corn Has Been Grown.

It normally requires several years fully to establish a new crop rotation with its accompanying system of fertilization. Figure 176 illustrates the establishment of a three-year-rotation of corn, oats, and clover. It is assumed that the land had been in corn the previous year. Since it is difficult to secure a good hay crop the first year from the spring seeding of clover, oats and field peas are grown on one field the first year for hay. The three regular crops are produced the second year, but not until the third season is the corn crop grown on clover sod. Longer rotations may require even a greater length of time to become fully established.

Frequently two or more separate rotations are used on the same farm.[3] Conditions which may justify a special additional rotation are:

(1) Where a cash crop such as potatoes is grown and the area of good potato soil is limited.

(2) To confine the production of heavy, green crops, such as corn silage to fields near the farm buildings.

(3) Where a part of the farm is subject to erosion, necessitating the less-frequent growing of cultivated crops, or their elimination from the rotation.

(4) In order that meadows on which aftermath grazing is to be practiced, may be conveniently located in respect to buildings, lanes, and water supply.

## 3. Fertilizing the Rotation

In determining the system of fertilization for field rotations, consider the individual crops as well as their sequence. The cash crops, particularly vegetables, should be fertilized more generously than crops grown for feed. Always fertilize liberally the crops that normally return the greatest acre profit. When this is done the residual effect of the fertilizer will frequently be adequate for the other crops.[4]

**Procedure:**

A. Fertilize grain and hay rotations.
B. Fertilize vegetables grown in field rotations.
C. Fertilize cotton rotations.
D. Fertilize special crops grown in field rotation.

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[3] A double-rotation system adapted to dairy farming is outlined and discussed in the General Information at the end of this chapter.

[4] See General Information at end of chapter for experimental results with rotations.

**A. Fertilize grain and hay rotations.** Emphasis has already been given to the importance of conserving and utilizing most advantageously the farm-manure supply, and of growing legumes as a means of furnishing nitrogen for the other crops of the rotation.[5] Separately or combined, these two factors can be considered absolutely essential to the economic production of grain and hay. The nitrogen needs of these crops must be supplied, largely at least, through legumes and manure. Fertilizer nitrogen may, under favorable conditions, be used in small amounts with profit. Because of the necessary overhead in the manufacture of mixed fertilizers, they will always be a relatively expensive source of nitrogen. Legumes, or legumes and manure, must be depended on for most of the nitrogen; and when legumes are grown frequently the available supply is increased to such an extent that additional nitrogen applied as a fertilizer becomes unprofitable. Economy in grain and hay production necessitates cropping systems and manuring practices which will largely, if not entirely, eliminate the need for complete fertilizers.

FIG. 177. ALFALFA GROWN IN ROTATION WITH GRAIN CROPS.

The nitrogen needs of grain and hay must be supplied, largely at least, through legumes and manure.

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[5] See Chapters V and VIII for manuring and leguming land.

The need for potash will depend on the character of the soil and on the disposition of the crops grown. Sandy and gravelly soils, as well as muck and peat, are more in need of potash than are the heavy-textured mineral soils. When the crops are largely fed to livestock, the resulting manure will normally meet any potash deficiency. Where potash is needed, purchase it as muriate of potash or as a mixed fertilizer high in potash such as the 0–20–10 or the 0–20–20 analysis. In a commercially mixed fertilizer with a low potash content, the cost of this constituent is prohibitive for grain and hay crops.

In grain farming where little livestock is kept, grow clover or alfalfa once in three years, and supply adequate potash as well as phosphorus as fertilizer. On livestock farms where the grain and roughage are used for feed and bedding, a legume once in four years will suffice. If considerable feed is purchased, clover once every five years will supply sufficient nitrogen for good yields.

If grain crops occupy the land for more than two consecutive years, it becomes necessary, except on soil well supplied with organic matter, to add nitrogen as well as phosphoric acid as fertilizer. Potash also will be needed under these conditions. In the common four-year rotation of corn, oats, wheat, and hay, the wheat will respond to nitrogen and often to potash also. If manure is available, it can be used advantageously for wheat. Otherwise, the wheat requires nitrogen and potash in addition to phosphoric acid, for good yields. Even under these conditions, wheat must sell at a high price to return a profit from the nitrogen and potash supplied in the ordinary grain fertilizer.

A similar need for nitrogen occurs where timothy is grown for several consecutive years. A good growth of clover with the first-year timothy will furnish adequate available nitrogen for the second-year hay. Unless a good clover crop is secured, top-dress timothy the second year with manure or a nitrogenous fertilizer. Even with good clover the first year, apply annually a similar treatment to timothy, beginning the third year. Except on soils that because of their rough or stony character are expensive to till, do not leave a seeding of clover and timothy for more than two years. This obviates the necessity of applying expensive nitrogenous fertilizers for timothy.

In some winter-wheat producing sections where the growing season is long enough to permit following corn with wheat, a rotation of corn, wheat, and one or more years of hay is followed. This rotation includes only two soil-depleting crops, and if the hay is largely clover and grown for but one year, it is a good rotation for land not subject to erosion.

Fig. 178. A Farm on which the Soil Is Well Fertilized.

This general system of soil treatment, consisting of lime, a phosphatic fertilizer material, and manure, is recognized as economically sound and permanently effective for livestock farms.

On livestock farms where most of the crops are fed and the residues used as bedding, the fertilizer problem is simplified. Under these conditions large yields can be secured permanently through the use of lime and a phosphatic fertilizing material. Grow clover or alfalfa regularly in the rotation, and conserve and apply the manure properly. The nitrogen needs of the grain crop can be fully supplied in this way.

In fact, on some dairy farms where alfalfa is grown regularly in the rotation or where large amounts of concentrates are purchased, excessive amounts of nitrogen are supplied, with the result that small-grain crops lodge or grow so rank as to injure the seeding. Apply lime once in the rotation as long as it is needed for the legume hay crop, and treat all the manure produced with 40 to 60 pounds to the ton of superphosphate or rock phosphate. Make an additional application of the phosphatic fertilizer material under certain conditions for unmanured grain crops. This general system of soil treatment, consisting of lime, a phosphatic fertilizer material, and manure, is recognized as economically sound and permanently effective for livestock farms.

*A well-fertilized grain rotation.* The rotation of corn, corn, oats, and clover is very common in the Corn Belt. A plan for its fertilization will suffice as a standard for grain farming as well as livestock farming in the Central Prairie Section. It is assumed that some manure is produced on the farm. Where this is not so, shorten the rotation to three years by the elimination of one of the corn crops, unless it is feasible to produce a legume green-manure crop with the first-year corn. Fertilize the rotation as follows:

Corn, 200 pounds superphosphate.
Corn, 10 tons superphosphated manure, or 400 to 600 pounds of superphosphate and 100 pounds of muriate of potash.
Oats, 2000 pounds ground limestone if needed for clover.
Clover, no fertilizer.

If rock phosphate is used instead of superphosphate, apply it at the rate of 800 to 1000 pounds to the acre once in the rotation. Where manure is used, mix the rock phosphate with it for the second-year corn, otherwise plow it under with the clover sod for first-year corn. Other forms of lime may be substituted for limestone where prices justify their use, and the lime may be applied for corn instead of for oats. Heavier initial applications of lime will be needed on very acid soils.

*Fertilizer for a dairy rotation.* The four-year rotation of silage corn, oats or mixed grains, and two years of clover and timothy is a representative dairy rotation. Fertilize it as follows:

Corn, 10 tons superphosphated manure, 2000 pounds limestone.
Oats or mixed grains, 300 pounds superphosphate.
Clover, no treatment.
Timothy (for hay or pasture), no treatment.

Other phosphatic fertilizer materials may be substituted for superphosphate, and other forms of lime for limestone, as in the previous rotation. Where rock phosphate is used, apply all of it—800 to 1000 pounds to the acre—with manure, for corn. A heavier initial application of lime may be needed. Until the lime requirement of the plowed soil for clover is fully satisfied, apply the material for oats rather than for corn.[6]

If this rotation is lengthened by leaving timothy on the land two additional years, treat it as follows: Top-dress the first of these two timothy crops with 8 to 10 tons of superphosphated manure to the acre. This treatment will suffice for the two additional years of hay. If superphosphated manure cannot be used, then fertilize the timothy in one of the following two ways: (1) In the fall after the first timothy crop has been harvested, apply with a drill or lime distributor 200 to 400 pounds of superphosphate to the acre. Top-dress each of the timothy crops in the early spring with 100 to 200 pounds to the acre of a nitrogenous material, such as nitrate of soda, sulfate of ammonia, or cyanamid. If conditions necessitate, the nitrogenous material may be broadcast by hand or with a Cyclone knapsack fertilizer distributor. (2) Top-dress both timothy crops in the early spring with 100 to 200 pounds to the acre of a high-analysis mixed fertilizer such as a 5–10–5, or with 50 to 100 pounds of a concentrated one, such as the 10–20–10.[7]

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[6] See General Information at end of chapter for the fertilization of other grain and hay rotations.

**B. Fertilize vegetables grown in field rotations.** Since the field-grown vegetable crops offer a higher net return to the acre, they justify a more expensive fertilizer treatment. When produced in a short rotation with grain and hay, the field-grown vegetables should receive all the fertilizer used in the rotation. If farm manure is available, it also can often be used to best advantage for the vegetable crop. When this crop is liberally fertilized, there will be adequate residual effect for the other crops, at least in a short rotation. So long as the additional fertilizer applied to the vegetable crop pays its

FIG. 179. FIELD-GROWN POTATOES.

When produced in a short rotation with grain and hay, the field-grown vegetables should receive all the fertilizer used in the rotation.

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[7] For alfalfa rotation see page 407.

way, the residual effect on the other crops is costing nothing. The practice of fertilizing liberally the crop in the rotation that offers the greatest net profit is sound.

When manure is applied, use in addition either superphosphate or a fertilizer composed largely of it. The choice between superphosphate and a mixed fertilizer depends on the rate at which the manure is applied, the amount of fertilizer to be used, the kind of crop, and the character of the soil. In general, considering the whole rotation, where manure is applied at the rate of fully 10 tons, and not more than five dollars' worth of fertilizer is to be applied to the acre, use superphosphate. With an increased fertilizer investment, use a complete fertilizer, such as the 4–12–4 or 5–10–5, at the rate of 400 to 600 pounds to the acre, or half as much 10–20–10. Where manure is not applied, use the same fertilizer but increase the amount 50 per cent. If, owing to a potash deficiency, the yield of the other crops in the rotation is reduced, use a fertilizer higher in potash, such as the 4–8–10, for the cash vegetable crop, especially where manure is not used, in order to make certain of an adequate residual effect of potash for the following crops.

The accompanying suggested system of fertilization for a three-year rotation of a field vegetable, small grain, and clover will serve as a standard for field-grown vegetables. The manure should be applied and plowed under in the fall.

| | |
|---|---|
| Potatoes | Manure and 500 pounds superphosphate, or 400 to 600 pounds of 4–12–4.<br>Without manure, 600 to 1000 pounds of 5–10–5 or 4–12–4, or 300 to 500 pounds of 10–20–10. |

Wheat, lime as needed for clover.
Clover, no treatment.

Where potato scab is troublesome, it is not practical to grow red clover or other lime-loving legumes in the rotation. The soil reaction should be maintained at a point favorable to scab control, and crops grown in the rotation that are tolerant to the required degree of acidity. If the area of good potato soil is limited, a separate short potato rotation may be established; or under extreme conditions potatoes may be grown continuously on the same land and a winter cover crop introduced to replenish, at least in part, the soil organic-matter supply.

**C. Fertilize cotton rotations.** Cotton is now grown in rotations throughout much of the Cotton Belt. Corn generally follows cotton in the rotation, though often cotton is grown for two consecutive years, as is corn in the Corn Belt. Winter oats or oats and vetch mixed follow corn, and they in turn are followed the same year by cowpeas. Tobacco, sweet potatoes, and other special crops may enter the cotton rotation. Catch crops and winter cover crops, including crimson clover, rye, vetch, burr clover, lespedeza, and cowpeas, are successfully brought into the more effective cotton rotations.

Cotton is a cash crop which requires liberal fertilization. It responds well to commercial fertilizers, and at normal prices gives a good return on the investment. Soils of much of the Cotton Belt are generally sandy in character and poorly supplied with organic matter. The crop requires relatively large amounts of plant-food. A 2-bale crop requires more of each of the three fertilizer constituents than a 100-bushel crop of corn. However, much more nitrogen and phosphoric acid are returned to the soil in cotton stalks than in corn stover. Manure is seldom available for cotton, and commercial fertilizer must be depended on to supplement the plant-food secured through legumes, green-manure crops, and crop residues.

Apply 800 to 1500 pounds of fertilizer to the acre for cotton. The percentage of nitrogen depends on the character of the soil and the frequency with which legumes have been grown. Ordinarily, a cotton fertilizer contains 3 to 6 per cent nitrogen. Use the 4–12–4, which is virtually a higher-grade 3–8–3, where the soil is fairly well supplied with organic matter or when legumes are grown regularly as catch crops. The more concentrated 6–18–6 should, when obtainable, replace the less-concentrated analyses. Where less nitrogen is supplied by the soil or by legume crops, use the 5–10–5, 10–20–10, or some other analysis approaching the 1–2–1 ratio.

The following rotation is adapted to much of the Cotton Belt, and with the fertilizer treatment given will produce good yields permanently.

Cotton (winter cover crop of crimson or of burr clover), 1000 pounds of 4–12–4 or 650 pounds of 6–18–6; 2000 pounds limestone when needed.

Corn (cowpeas or soybeans in the row or broadcast at last cultivation), no treatment, except on very sandy soils and then apply 100 pounds nitrate of soda or sulfate of ammonia unless a good clover crop is plowed under.

Oats and vetch (cowpeas as green manure), 200 to 300 pounds of 4–12–4 or 150 to 200 pounds of 6–18–6.

**D. Fertilize special crops grown in field rotations.** In addition to grain and hay crops, field-grown vegetables, and cotton, other crops are produced in field rotations which, though of considerable local importance, are of minor general interest because of being grown in restricted sections. Of these, tobacco, peanuts, sweet potatoes, sugar beets, sugar cane, sorghum, rice, buckwheat, and flax are deserving of consideration. Study the fertilizer recommendations of your state agricultural college in determining the fertilizer treatment for these or other special crops.

*Tobacco.* Tobacco has an unusually high potash requirement. Its quality may be injured by excessive applications of nitrogen or by a fertilizer with a high chlorine content. Excessive amounts of phosphoric acid may cause too rapid ripening. While tobacco will do well on fairly acid soils, lime should be applied as needed. Fertilizer for the light-colored, bright tobacco grown extensively in Virginia and the Carolinas should contain relatively little nitrogen. It should not be grown on rich soils, should not follow legume sod and should not be manured. For the dark-colored types produced in the northern states, and Burley tobacco grown extensively in Kentucky, use a fertilizer with more nitrogen, and apply farm manure if available. Plan to grow these darker types of tobacco on clover or other legume sod. Because of the influence of the fertilizer on the quality of the crop, the fertilization of tobacco should receive special study on the part of the individual producer.

FIG. 180. FIELD OF TOBACCO. (U. S. Dept. of Agr., Bureau of Plant Industry.)

Tobacco has an unusually high potash requirement.

In fertilizing tobacco, at least half the nitrogen should be supplied in cottonseed meal, castor pomace, animal tankage, or some other organic form. The remainder of the nitrogen may come from sulfate of ammonia or nitrate of soda. Superphosphate is a satisfactory source of the phosphoric acid. In selecting the potash material, avoid supplying an excess of chlorine, though 1 to 2 per cent is considered desirable. Consequently, up to 4 pounds of muriate of potash may be used in each hundred pounds of fertilizer. Any additional potash should be supplied as sulfate of potash. Tobacco frequently requires magnesia in small quantities of 1 to 2 per cent in the fertilizers. This may be secured by adding magnesium sulfate, or by using a sufficient amount of sulfate of potash magnesia.

For light-colored tobacco, apply 600 to 900 pounds to the acre of a 4–16–4, or the equivalent amounts of the three nutrients in a mixture of greater or lesser concentration. On sandy soils both the nitrogen and potash should be increased about 25 per cent. For dark-colored tobacco, apply 400 to 700 pounds to the acre of a 4–12–5, or the amount of some other concentration necessary to supply the same quantity of nitrogen, phosphoric acid, and potash. Manure for most types of tobacco may be applied in addition to the fertilizer, but when it is used, the rate of application of fertilizer may be reduced.

For cigar-leaf tobacco in the Connecticut Valley, use a fertilizer with approximately a 1–1–1 ratio. On areas liberally fertilized in past years the phosphoric acid may be somewhat reduced. The rate of application normally supplies 100 to 200 pounds to the acre of each of the plant-food constituents. Unless dolomitic limestone is applied, or used in the fertilizer mixture, 12 to 15 pounds of magnesium should be supplied to the acre for each crop.

*Sweet potatoes.* The quality of sweet potatoes, like that of tobacco, is materially influenced by their fertilization. The shape of the potato, as well as its cooking quality, may be modified by the fertilizer treatment. Use a complete fertilizer, relatively low in nitrogen but high in both phosphoric acid and potash, for sweet potatoes. Make certain that the nitrogen comes, partly at least, from animal ammoniates or cottonseed meal. The 4–8–10 and 3–8–8 mixtures are well adapted to sweet potatoes on sandy soils. Apply at the rate of 600 to 1000 pounds to the acre.

*Peanuts.* The peanut is a legume, and when inoculated can use atmospheric nitrogen. In common with other legumes, peanuts should be fertilized with superphosphate or a fertilizer composed of superphosphate and a potash salt. When they follow a well-fertilized cotton crop, additional fertilizer need not be applied. If the soil is very acid, lime at the rate of 2000 pounds of ground limestone, or its equivalent in other forms of lime, to the acre. Where a mixed fertilizer is necessary, use the 4–12–4 or 5–10–5, or other analyses with the 1–3–1 or 1–2–1 ratios. Under conditions requiring additional potash, apply the 5–10–10 analysis.

FIG. 181. A NEW JERSEY SWEET-POTATO FIELD. (N. J. Agr. Exp. Sta.)

**Use a complete fertilizer, relatively low in nitrogen but high in both phosphoric acid and potash, for sweet potatoes.**

*Sugar beets, sugar cane, and sorghum.* Sugar beets are extremely sensitive to soil acidity. Lime must be used if the soil is acid. Base the rate on the lime requirement of the soil, and apply enough to make the surface soil neutral. When these crops are grown on mineral soils, fertilize with a 4–16–4, 4–12–4, or a more-concentrated mixture with a similar ratio, and apply at the rate of 300 to 500 pounds to the acre, and with equal parts of superphosphate and sulfate of potash when grown on muck. Use sulfate of potash to furnish the potash, and nitrate of soda and sulfate of ammonia to furnish the nitrogen in fertilizer mixtures for sugar beets. Fertilize sugar cane with 400 to 600 pounds to the acre of a 6–8–4 fertilizer. Where desired, the phosphoric acid and potash salt may be applied in the fall, and the nitrogen as a top-dressing in the form of sulfate of ammonia or nitrate of soda in the spring.

FIG. 182. FIELD OF PEANUTS. (Va. Agr. Exp. Sta.)

In common with other legumes, peanuts should be fertilized with superphosphate or a fertilizer composed of superphosphate and a potash salt.

Where sorghum is grown for roughage, produce it in a rotation that makes unnecessary any treatment other than superphosphate. Where this crop is grown for sirup, superphosphate suffices on sod ground, on soils well supplied with organic matter and on those recently manured. Otherwise, use 400 pounds of a 4–12–4 fertilizer to the acre.

*Rice, buckwheat, and flax.* Fertilize rice, in common with other field-grown cereals, largely with superphosphate. Of the factory-mixed fertilizers, the 4–16–4 and 4–12–4 are best suited to this crop.

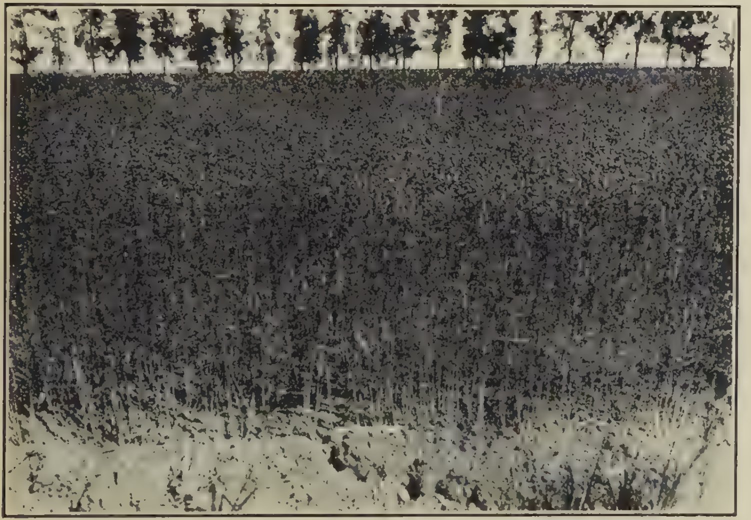

FIG. 183. FIELD OF FLAX. (Agronomy Dept., Ill. Agr. Exp. Sta.)

Except on extremely poor soils fertilize buckwheat and flax with superphosphate. Apply 200 to 400 pounds to the acre.

Buckwheat and flax are short-season crops grown during the season when the soil is furnishing available nitrogen and potash at a rapid rate. Except on extremely poor soils, fertilize buckwheat and flax with superphosphate. Apply 200 to 400 pounds to the acre. Where poor soil necessitates the use of a complete fertilizer, use a 4–16–4 or a 4–12–4 analysis at the rate of 200 to 300 pounds to the acre.

## TABLE XLI *

### THE SOIL-PRODUCTIVITY OR CONSERVATION BALANCE OF CROP LAND

(As indicated by cropping and soil-management practices in any one-year period.)

Soil-Building Practices

**CREDITS**

| A. Meadows Mowed for Hay or Grazed | Acres *a* | Factor *b* | Points *a* × *b* |
|---|---|---|---|
| 1. 50% or more of legumes, seeded 1 yr. before | ...... | +2.0 | + .... |
| 2. 50% or more of legumes, seeded 2 yrs. before | ...... | +0.5 | + .... |
| 3. 25% to 50% of legumes, seeded 1 yr. before | ...... | +1.0 | + .... |
| 4. 25% to 50% of legumes, seeded 2 yrs. before | ...... | +0.25 | + .... |
| 5. Less than 25% of legumes, seeded 1 yr. before. (If in meadow additional years than stated give no credit or debit.) | ...... | +0.25 | + .... |
| | | A. Total | + .... |

| B. Crops or Crop Residues Plowed Under | Acres *a* | Factor *b* | Points *a* × *b* |
|---|---|---|---|
| 6. Meadow—50% or more of legumes, first growth | ...... | +3.0 | + .... |
| 7. Meadow—50% or more of legumes, second growth only | ...... | +1.0 | + .... |
| 8. Meadow—less than 50% of legumes, first growth | ...... | +1.0 | + .... |
| 9. Meadow—less than 50% of legumes, second growth only | ...... | +0.25 | + .... |
| 10. Green-manure crops | | | |
| *a*. Sweet clover | ...... | +2.0 | + .... |
| *b*. Soybeans | ...... | +1.0 | + .... |
| *c*. Buckwheat | ...... | +0.5 | + .... |
| *d*. Rye or other small grains | ...... | +0.5 | + .... |
| 11. Crop residues (straw, cornstalks, or cotton stalks) | ...... | +0.25 | + .... |
| | | B. Total | + .... |

| C. Added to Soil During Crop Year | Tons *a* | Factor *b* | Points *a* × *b* |
|---|---|---|---|
| 12. Fertilizer | | | |
| *a*. Less than 20% plant-food | ...... | +1.5 | + .... |
| *b*. 20% to 30% plant-food | ...... | +2.25 | + .... |
| *c*. Over 30% plant-food | ...... | +3.0 | + .... |
| 13. Lime | | | |
| *a*. Limestone | ...... | +0.5 | + .... |
| *b*. Hydrated lime | ...... | +0.7 | + .... |
| *c*. Burned lime | ...... | +1.0 | + .... |
| 14. Manure | | | |
| *a*. Cow or mixed | ...... | +0.1 | + .... |
| *b*. Sheep | ...... | +0.2 | + .... |
| *c*. Poultry | ...... | +0.2 | + .... |
| | | C. Total | + .... |

TABLE XLI—*Continued*

Soil-Depleting Practices

**DEBITS**

| D. Row and Drill Crops Harvested | Acres *a* | Factor *b* | Points *a* × *b* |
|---|---|---|---|
| 1. Non-legume row crops.................... | ...... | −2.0 | − .... |
| 2. Non-legume drilled crops.................. | ...... | −1.0 | − .... |
| 3. Field beans, peas, soybeans................ | ...... | −0.5 | − .... |
| | | D. Total | − .... |

| E. Losses on Land Subject to Erosion | Acres *a* | Factor *b* | Points *a* × *b* |
|---|---|---|---|
| 4. Rowed crops with no provision for erosion control.............................. | ...... | −1.0 | − .... |
| 5. Winter grain.............................. | ...... | −0.5 | − .... |
| 6. Rowed and spring drilled crops grown on contour or in strips, or protected by diversion ditch.............................. | ...... | −0.5 | − .... |
| (In sod throughout the year, no debit) | | E. Total | − .... |

| F. Waste of Manure Exposed Before Spreading | Tons *a* | Months *b* | Factor *c* | Points *a*×*b*×*c* |
|---|---|---|---|---|
| 7. | | | | |
| *a*. Cow and mixed manure......... | ...... | ...... | −0.1 | − .... |
| *b*. Sheep and poultry manure....... | ...... | ...... | −0.2 | − .... |
| | | | F. Total | − .... |

* "The Soil Productivity Balance of Cropland," by J. W. Slipher, Ohio State University and U. S. Dept. of Agr. cooperating.

## 4. EVALUATING THE SOIL-MANAGEMENT PROGRAM

A plan for evaluating the effectiveness of the cropping and fertilizer system in soil conservation has been developed for the State of Ohio.[7] A plus-value factor is assigned for each soil-building practice, and a minus-value factor for each soil-depleting practice. The number of acres multiplied by the assigned factor gives the total credit or debit for each cropping and soil-management practice. If the total of all assigned factors is zero or above, the productivity is being maintained; but if less than zero (a minus figure), the soil is being depleted. The degree of conservation or depletion is indicated by the size of the plus or minus factor.

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[7] "The Soil Productivity Balance of Cropland," by J. W. Slipher, Ohio State University and U. S. Dept. of Agr. coöperating.

To determine conservation factor, add totals A, B, and C; then total D, E, and F. Subtract the smaller figure from the larger and divide the difference by the total acres of cropland.

This plan for judging the soil-productivity balance is reproduced in Table XLI in a somewhat simplified and modified form.

## GENERAL INFORMATION

### 1. Field-Crop Rotation

**A. The advantages of rotating crops.** The growing of crops in a well-planned sequence has many advantages over the single-crop system. These advantages are briefly stated in the list which follows:

(1) Makes possible the growing of a legume soil-improving crop or a sod crop on all the fields of the farm.
(2) Permits seeding grass and clover with a nurse crop.
(3) Makes possible the application of manure to the various fields without applying it for a crop that responds poorly.
(4) Provides for the alternating of crops having different root systems with those differing in their demands on the soil nutrients.
(5) Assists in the control of insect injury and crop diseases.
(6) Helps in weed eradication.
(7) Reduces soil loss by erosion.
(8) Lessens the loss of nitrates through drainage water.

The single-crop system of farming can be condemned because:

(1) It is conducive to soil depletion.
(2) Labor cannot be efficiently utilized.
(3) It provides only a single source of income which is inadequate in years when the yield or the price of the crop grown is low.

**B. A well-planned double-rotation system for a dairy farm.** In Fig. 184 is given the field arrangement, the rotation system, and the soil treatment for a 100-acre dairy farm. A five-year rotation of silage corn, mixed grains, and three years of hay is followed on the five 12½-acre fields, *A, B, C, D,* and *E.* A three-year rotation of potatoes, cabbage, or other cultivated crop the first year, followed by rye or spring grain the second, and pasture the third, is followed on fields *X, Y,* and *Z.* Corn or soybeans for grain feed may be substituted for the cash crop. Provision is made for a 6-acre permanent pasture in addition to 20 acres of pasture in the three-year rotation. If additional pasture is needed the third year, alfalfa can be used for grazing.

<table>
<tr><td colspan="2">Field A.<br>12½ A.<br>Silage Corn<br>1 Ton Limestone<br>10 Tons Superphosphated Manure</td><td colspan="2">Field B.<br>12½A.<br>Spring Grain<br>400 lb. Superphosphate</td><td>Field C.<br>12½ A.<br>Alfalfa Hay<br>No Treatment</td><td>Field D.<br>12½ A.<br>Alfalfa Hay<br>No Treatment</td></tr>
<tr><td>Farm Bldgs.</td><td colspan="4">Permanent Pasture 6 A.—600 lb. Superphosphate Every 4 Years</td><td rowspan="2">Field E.<br>12½ A.<br>Alfalfa Hay<br>No Treatment</td></tr>
<tr><td colspan="2">Field X.<br>10 A.<br>Potatoes, Beans or Cabbage<br>10 Tons Superphosphated Manure or 800 lb. 4–16–4</td><td colspan="2">Field Y.<br>10 A.<br>Rye or Spring grain for Pasture<br>No Fertilizer 1 Ton of Limestone on Alternate Rotations</td><td>Field Z.<br>10 A.<br>Sweet Clover Pasture<br>No Treatment</td></tr>
</table>

Fig. 184. A Double-Rotation System with Soil Treatment.

The hay seeding in the five-year rotation should include alfalfa, Ladino clover, or some other perennial legume adapted to the soil and climate. In the three-year rotation, the rye or spring grain may be grazed if needed for pasture, and should be seeded with a grass and legume mixture to be grazed the third year. When additional pasture is needed in midsummer, the aftermath growth of hay in the five-year rotation may also be grazed. This cropping system with its accompanying fertilization should supply adequate hay, silage, and pasture for a 25-cow dairy, and in addition a cash crop, or a considerable proportion of the necessary grain feed.

**C. Fertilizing rotations.** A supplemental list of representative field-crop rotations for the United States, with suggested fertilizer treatment, is given for reference:

(1) Corn, 400 to 600 pounds superphosphate or 0–20–20; oats, limestone as needed for clover; clover, none.
(2) Corn, 400 pounds superphosphate; oats, none; wheat, limestone as needed for clover, 200 to 400 pounds superphosphate and manure, or 200 to 300 pounds 5–20–5; clover, none.
(3) Corn, 300 to 400 pounds superphosphate or 0–20–20; soybeans, none; wheat, limestone as needed for clover, 200 to 300 pounds superphosphate or 5–20–5; clover, none.
(4) Corn, limestone as needed for clover, 10 tons superphosphated manure; oats, none; clover, none; wheat, 200 to 300 pounds 5–20–5 and sweet clover seeded in wheat as green-manure crop.

By introducing soybeans after corn, this can be made a five-year rotation. Change the treatment by applying the lime for soybeans or oats instead of for corn, and use 200 pounds of superphosphate for oats.

(5) Tobacco, 2000 pounds limestone, 10 tons manure, 800 pounds mixed fertilizer, such as a 5–20–5; wheat, none; clover, none.

By introducing corn after tobacco this can be changed to a four-year rotation. Spring grain, such as oats or barley, can be grown instead of wheat. Fertilize tobacco as in the three-year rotation, and leave the other three crops untreated.

(6) Cotton, 800 to 1000 pounds 4–12–4, 2000 pounds limestone when needed; corn, 8 to 10 tons of manure or 100 pounds sulfate of ammonia or nitrate of soda; crimson clover and cowpeas, no treatment.

The crimson clover can be used as green manure, and peanuts instead of cowpeas, grown the third year. Apply 200 to 300 pounds of superphosphate and 50 to 75 pounds of muriate of potash for the peanuts.

(7) Corn, 200 pounds superphosphate; beans, 2000 pounds limestone, 400 pounds 4–16–4; wheat, 200 pounds 4–16–4; clover, no treatment.

## 2. Experimental Results

The effect of crop rotation on yields has been determined by various experiment stations. Results secured by the Ohio and Illinois Stations are of particular value in showing the need of rotating field crops, and of combining grain and live-stock farming.

**A. Ohio results.** At the Ohio Station, since 1894, wheat has been grown (1) continuously; (2) in a five-year rotation of corn, oats, wheat, clover, timothy; and (3) in a three-year rotation of potatoes, wheat, and clover. In all three instances the wheat has received the following complete fertilizer treatment to the acre: 120 pounds nitrate of soda, 50 pounds dried blood, 160 pounds superphosphate, and 100 pounds muriate of potash. The same rate of application of superphosphate has also been used alone in the five-year and the three-year rotations. The average annual treatment for the rotation is given in terms of nitrogen, phosphoric acid, and potash, in Table XLII.

TABLE XLII

Treatment of Chio Rotations

| Cropping System | Superphosphate Treatment, Pounds Phosphoric Acid | Complete Fertilizer Treatment, Pounds Nitrogen, Phosphoric Acid, and Potash, Respectively |
|---|---|---|
| Continuous wheat... | .... | 24.3<br>25.6<br>50.0 |
| Five-year rotation.. | 10.2 | 14.3<br>10.2<br>26.0 |
| Three-year rotation.. | 17.1 | 12.0<br>17.1<br>33.3 |

The average annual yield of wheat over the thirty-year period is given in Table XLIII.

TABLE XLIII

Annual Yield of Wheat—Ohio Rotations

| Cropping System | Bushels Wheat per Acre | | |
|---|---|---|---|
| | Unfertilized | Super-phosphate | Complete Fertilizer |
| Continuous wheat...... | 7.3 | .... | 19.2 |
| Five-year rotation...... | 10.5 | 18.8 | 26.8 |
| Three-year rotation..... | 26.0 | 35.7 | 37.9 |

These results show clearly the value of a short rotation. They also show the efficiency of superphosphate as a wheat fertilizer in the three-year rotation, with a yield of 35.7 bushels with superphosphate alone, in comparison to 26.8 bushels in the five-year rotation, and 19.2 bushels in continuous cropping where complete fertilizer was used. Note also that the wheat yield with superphosphate alone in the five-year rotation is nearly as large as with the complete fertilizer treatment in continuous cropping.

A comparison of grain farming with livestock farming has been made by the Ohio Experiment Station. A rotation of corn, soybeans, wheat, and clover has been followed. In the grain-farming system the clover has been returned to the land as green manure. The results summarized in Table XLIV indicate larger yields of corn and soybeans in the livestock system, but a slightly larger average yield of wheat in the grain system. From the practical standpoint, the livestock system is superior since the clover crop has been utilized as feed.

TABLE XLIV

Ohio Results Over Seven-Year Period

| | Average Acre Yields in Bushels | | | |
|---|---|---|---|---|
| | Corn | Soybeans | Wheat | Clover |
| Grain farming........... | 63.3 | 19.0 | 29.7 | ........ |
| Livestock farming....... | 68.2 | 22.9 | 27.1 | 2.14 tons |

**B. Illinois results.** At the Illinois Station on typical prairie soil of the Corn Belt, corn has been grown both with and without fertilizer and manure since 1904: first, in continuous culture; second, a two-year rotation of corn and oats with clover seeded in the oats as a green manure; and third, a three-year rotation of corn, oats, and red clover. A similar cropping system, but without fertilizer and manure, had been followed for twenty-five years or more previous to 1904. The average corn yields are given in Table XLV.[8]

TABLE XLV

Corn Yields—Illinois Experiment

| | Continuous Cropping: Corn. Bu. Corn | Two-Year Rotation: Corn and Oats. Bu. Corn | Three-Year Rotation: Corn, Oats, and Clover. Bu. Corn |
|---|---|---|---|
| No treatment................ | 22.9 | 33.6 | 52.1 |
| Lime, manure, and phosphorus. | 42.4 | 54.6 | 67.7 |

The value of a rotation in corn production, both with and without lime, manure, and fertilizer, is shown by these results. It is of interest to note that corn has yielded nearly 10 bushels more to the acre without treatment in the three-year rotation, than with lime, manure, and a phosphatic fertilizer material in continuous culture.

In another experiment at the Illinois Station, farm manure has been compared with crop residues. Since the manure has

TABLE XLVI

Illinois Results—1902 to 1920

| Treatment | Average Acre Yields, in Bushels, of 14 Corn Crops, 15 Oat Crops, and 7 Wheat Crops | | |
|---|---|---|---|
| | Corn | Oats | Wheat |
| Crop residues (grain farming)...... | 85.5 | 59.8 | 45.9 |
| Manure (livestock farming)....... | 87.2 | 62.4 | 43.3 |

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[8] Yields represent averages for the years 1907 to 1913, 1919 and 1925, the only instances in which corn was grown in all rotations.

been applied in the approximate amounts that would be produced in a livestock system, the yields secured in the experiment may be considered representative of grain and livestock farming. They are given in Table XLVI.

A rotation of corn, oats, wheat, and clover was followed in this experiment. Soybeans were substituted when clover failed. Yields of legumes have not been included. They were cut for hay in the livestock system and at times threshed for seed in the grain system. Note that there is little difference in the yield of grain crops in either system. Exceptionally good yields have been secured by the use of limestone and bone meal, but over a period of years it has been found that potash is essential in addition to phosphorus in grain farming.

## COMMUNITY STUDIES

Visit several typical general farms of the community, and secure the following information relative to the management of the field soils.

1. List the field rotation or rotations being followed on each farm.
2. Secure information relative to the soil treatment employed for each rotation.
3. Plan a rotation which shall include the more important field crops grown in the community. Outline a system of soil treatment for this rotation.

## PROBLEMS

1. Start with a wheat field of 100 acres. Divide into five equal-sized fields, and develop a five-year rotation of corn, oats, wheat, clover, and timothy. Indicate by diagram the crops on each field annually until the rotation is finally established.
2. Calculate how much more wheat was secured at the Ohio Station from the application of superphosphate in a three-year rotation than from an application of complete fertilizer in a five-year rotation. (Refer to Tables XLII and XLIII.)

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Crop Rotations. S. C. Ext. Bul. 39.

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Fertilizers for Field Crops in Louisiana. La. Bul. 167.
Fertilizers for Tobacco. Wis. Bul. 413.
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Fertilizing Farm Crops. Pa. Cir. 208.
Fertilizing Field Crops in Ohio. Ohio Bul. 136.
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Tobacco Culture in Maryland. Md. Ext. Bul. 65.

# CHAPTER X

## MANAGING PASTURE SOILS

Pastures provide the cheapest feed for farm animals. It has been estimated that they furnish two-fifths of the total feed consumed by the livestock of the United States. The dairy and sheep industries are largely dependent on good pastures. Milk and its products, as well as wool and mutton, can be produced at the lowest unit cost when animals are on pasture. Good pastures are almost as essential in the economic production of beef and in raising and maintaining horses as they are in the dairy and sheep industries. Even in hog production, pastures should be utilized to a considerable extent.

Fig. 185. A Well-Grazed Permanent Pasture.

Pastures provide the cheapest feed for farm animals.

The area devoted to pastures in this country is greater than that used for the production of field crops. It consists largely of land that cannot be economically cultivated. Of greatest extent are the areas that are either too rough or too stony to be plowed. The range pastures of the West include vast areas unsuited to cropping because of inadequate rainfall, while in the humid sections scattering areas of wet land are pastured. The development of the livestock industry in sections where the land is largely suited to the production of cultivated crops has resulted in the pasturing of certain regular rotation crops, and in some instances in introducing special pasture crops into the rotation.

Fig. 186. Permanent Pasture on Good Land.

Permanent pastures should not be confined to the poorest land on the farm. In fact, land should never be considered too good for pasture.

In general, pastures have not received the attention they deserve, and too often they have been entirely neglected. As a result, American pastures have become poorer from decade to decade, as shown by a continued reduction in their carrying capacity. In many instances these more or less depleted pastures are good for short periods during the spring and fall, but are poor the remainder of the grazing season. When properly managed and fertilized, the soil of pastured land increases in fertility; and, as a result, the carrying capacity of the pasture becomes greater with use, and the period of good grazing longer.

Permanent pastures should not be confined to the poorest land of the farm. In fact, land should never be considered too good to be used for pasture. A good pasture when properly managed may produce as much and sometimes more feed than an equal area of grain, hay, or silage. A good permanent pasture should support one mature cow, or its equivalent, to the acre throughout most of the grazing season. The practice of renting or buying additional poor pasture land for the grazing of young and dry stock is a poor substitute for improving the carrying capacity and the quality of the existing pasture. Because of the low mineral and low protein content and the unpalatability of the herbage on poor pastures, animals are never so well nourished as they are on good pastures. Poor pastures, irrespective of acreage, never solve the problem of adequate, good-quality herbage during the seasonal period of low productivity.[1]

**Operations:**

1. Establishing a permanent pasture on plowable land.
2. Improving the non-plowable pasture.
3. Managing permanent pastures.
4. Incorporating pasture in the rotation.
5. Growing annual pasture crops.

## 1. Establishing a Permanent Pasture on Plowable Land

Pastures consisting of perennial plants, such as bluegrass and white clover, or of self-seeding annuals, such as Lespedeza and trefoil, which occupy the land continuously year after year, are known as *permanent pastures.* They may consist of either the native vegetation or the sward resulting from the seeding of a grass mixture. Some of the best permanent pastures today have been established by plowing, fertilizing, and reseeding old depleted pastures or meadow lands.

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[1] See General Information at end of chapter for location of pasture areas in United States and character of vegetation in each.

**Procedure:**

- A. Plow and fit the seed-bed.
- B. Apply lime and superphosphate.
- C. Seed.
- D. Regulate grazing the first year.

**A. Plow and fit the seed-bed.** In improving a badly depleted pasture, or in establishing a new one on land that can readily be tilled, the first step is to plow.[2] Where the land is in sod, plow in the fall in order that the sod turned under may partially decompose during the winter and early spring. The ground may be left in the rough over winter and the seed-bed prepared in the spring in the usual manner. When practicable, crop the field for a year or two before seeding down in order to destroy weed seed and to permit the thorough rotting of the old sod. Prepare the seed-bed especially well, as the seeds of the pasture plants are small, and a good stand cannot be secured in a cloddy soil. If the supply of manure is adequate and the soil poor, apply a light dressing to the pasture field prior to plowing.

Many run-down pastures can be successfully improved without plowing and seeding. In general, seeding should be resorted to only when new pastures are being established; where existing pastures are extremely poor and contain little or no white clover, or where, regardless of cost, conditions necessitate a pasture of maximum carrying capacity. Otherwise, even on plowable land, improve the established sward in the way recommended for the non-plowable pasture.

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[2] See Chapter IV, Tilling the Soil.

**B. Apply lime and superphosphate.** The best time to lime and fertilize pastures is when they are being reseeded. The soil should be tested and if found acid, lime should be applied in the necessary amount to satisfy the lime requirement of the plowed soil for the pasture plants to be sown. Both Kentucky bluegrass and the white clovers[3] do best where soils are well supplied with lime. If more than a ton of limestone is required to the acre, apply half of it before plowing and half afterwards.

FIG. 187. PASTURE IN THE BLUEGRASS REGION OF KENTUCKY. (Agronomy Dept., Ky. Agr. Exp. Sta.)

Both Kentucky bluegrass and the white clovers do best where soils are well supplied with lime.

A heavy application of a phosphatic fertilizer material is essential. Phosphorus is the real fertilizer essential on most soils for good bluegrass-white clover pastures. The best time to apply it is when the pasture is being seeded. The heavier the application the longer will be the time before more will be required as top-dressings. Superphosphate, rock phosphate, or basic slag may be used. Apply at the rate of at least 600 pounds to the acre. An 800- or a 1000-pound application would be even better. The application should be made to the plowed soil, preferably with a lime distributor, and thoroughly disked or harrowed into the surface 2 or 3 inches of soil. If soils are sandy in character or the fertility level low, apply in addition to the phosphorus at least 100 pounds of muriate of potash to the acre. An application of 600 pounds of a 0–20–10 fertilizer will supply both phosphorus and potash.

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[3] See General Information at end of chapter for the kinds of white clover.

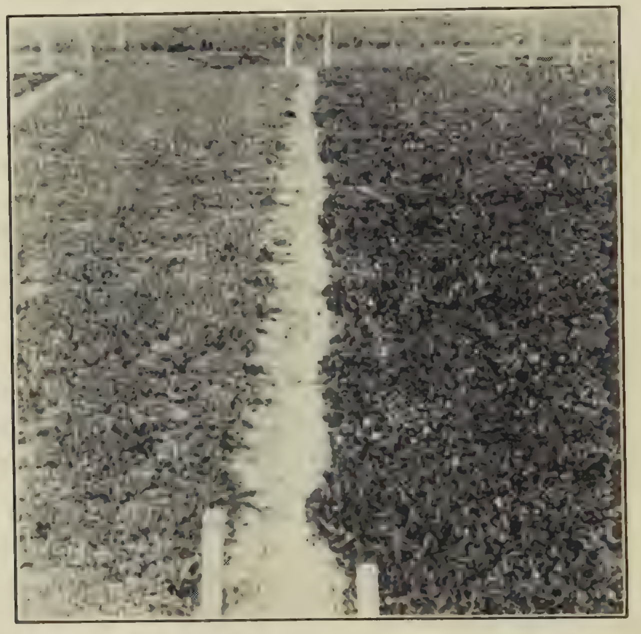

FIG. 188. WHITE CLOVER IMPROVES THE PASTURE SWARD.

Kentucky bluegrass seeded on left. Kentucky bluegrass plus 1 pound to the acre of white clover seeded on right.

The better practice is to seed the pasture mixture alone. Include 1 or 2 pounds of white clover seed to the acre.

**C. Seed.** The pasture mixture may be seeded alone or with a companion or nurse crop. The better practice is to seed alone. This will permit grazing the first season, and where the soil is liberally fertilized and a good seed mixture sown, the grazing secured the year of seeding will more than offset the feeding value of the companion crop. If seeding alone it is important that the seed-bed be free from weed seeds, for otherwise the crowding of weeds might retard the growth of the new seeding as much as would a companion crop. Where the land is very foul, grow a cultivated crop for one year before seeding. In sections where buckwheat is produced, it may be substituted for the cultivated crop. Unless weeds have been subdued the previous year, practice clean culture, that is, till frequently during the spring and early summer, and delay seeding the pasture mixture until July.

If hay is to be harvested for a year or two before grazing the pasture, clover or alfalfa or both should be included in the seeding mixture. Where this practice is followed, the seeding should be made with a small grain companion crop. Usually where land is seeded down to permanent pasture an immediate increase in the acreage of pasture is desired, and in general better results may be expected if grazing starts the year of seeding. If a companion crop is used under these conditions, it should be either pastured off or cut green for hay rather than left to mature grain. On land that is suited to sweet clover, this legume will be found an excellent companion crop since it can be grazed in the fall of the year sown and again the next spring and summer. An essential to success with the pasture seeding is early and close grazing of the sweet clover the second year in order to prevent its crowding the permanent pasture seeding.

There is no best seed mixture for permanent pastures. Obviously that will vary with climatic and soil conditions, as well as with the seeding practice followed. The rate of seeding should be 20 to 40 pounds to the acre depending on whether or not the mixture contains orchard grass or a meadow seeding in addition to the strictly pasture plants. The two seed mixtures on this page are suited to much of the northeast and north-central sections of the country. (See Section 1*a* and 1*b*, Fig. 206.)

Orchard grass may be added to either of these mixtures. If included, use at least 8 to 10 pounds to the acre since with a lighter rate of seeding the orchard grass develops in scattering bunches. Under special conditions other grasses or legumes suited to Section I may be substituted for or added to those specified in the mixtures.

MIXTURE 1 TO BE SEEDED FOR GRAZING ONLY

| | Pounds per Acre |
|---|---|
| Kentucky bluegrass | 8 |
| Red top | 3 |
| Timothy | 5 |
| Perennial rye grass | 5 |
| Wild white clover | 1 |
| Total | 22 |

MIXTURE 2 TO BE SEEDED WHERE HAY IS TO BE CUT FOR ONE OR TWO YEARS AND THEN GRAZED

| | Pounds per Acre |
|---|---|
| Timothy | 8 |
| Alfalfa | 4 |
| Kentucky bluegrass | 6 |
| Red and alsike | 4 |
| Canada bluegrass | 2 |
| Ladino white clover | 1 |
| Total | 25 |

In selecting the pasture mixture, make certain that the seed is of good quality. Many pasture mixtures on the market are composed of low-grade seed. Grass seed frequently is low in germination qualities. Domestic perennial rye grass is less hardy than the imported seed. Wild white clover seed has recently become available on the American market. It is produced extensively in England, and most commercial seed stocks are imported. It is not the same as the white Dutch clover. The wild white is a true perennial, living on from year to year; the white Dutch is a biennial. The wild white differs also from the white Dutch in that it has smaller leaves and a more pronounced creeping habit. It is often superior to the white Dutch for both pastures and lawns in cool climates. In the less severe climate of the South and Central West, the white Dutch is often considered superior to the wild white. The Ladino white clover is a large growing type which will not stand so close grazing as the other two.

Much progress has been made within recent years in developing improved pasture strains of grasses, especially timothy, orchard grass, and rye grass. Unfortunately, these grazing types are not available on the commercial market, but no doubt they will be in the near future. When they become available and the price is not prohibitive, use them in the pasture mixture.

In the southeastern states (Pasture areas 2*a* and 2*b*, Fig. 206), it is often necessary to establish grass by the use of stolons instead of seed. However, the adapted legumes are seeded the same as farther north. In Florida domestic rye grass is sometimes seeded in the fall for winter grazing. Before deciding definitely on the seeding mixture for the permanent pasture, consult your state college of agriculture and experiment station or your local county agent for mixtures recommended for your locality.

**D. Regulate grazing the first year.** Some precaution should be taken in grazing the newly seeded pasture. It should be permitted to make a growth of 3 to 4 inches before grazing begins. Animals should be kept off the pasture when the topsoil is wet. Avoid continuous grazing, but do not make the common mistake of undergrazing. If there is a good proportion of white clover in the pasture, it is surprising how closely the pasture may be grazed without injuring it. In fact, close grazing is essential for best results with this type of pasture. Undergrazing results in injury to the white clover plants by crowding and shading. After the herbage is grazed down as short as a clipped lawn, remove the animals and keep them off the pasture until a new growth of 4 inches has developed. White Dutch clover also should be closely grazed, but Ladino requires less close grazing.[4]

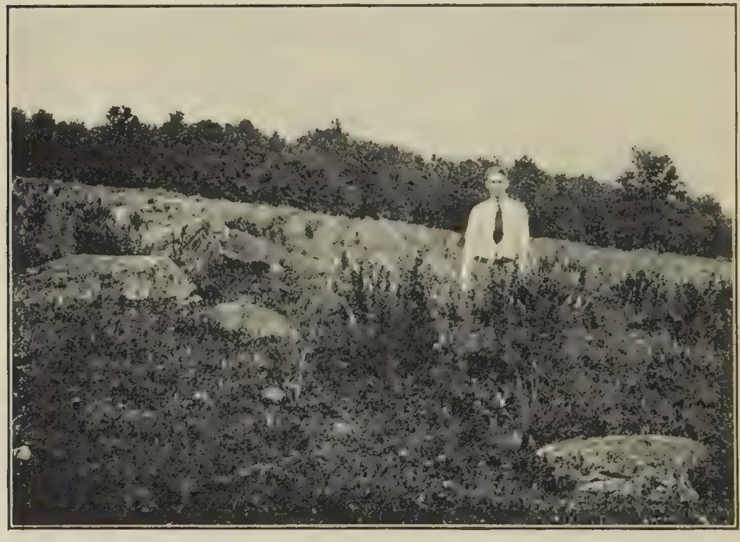

FIG. 189. A NON-PLOWABLE PASTURE. (Agronomy Dept., New York State Col. of Agr.)

Many pastures are too rough and stony to be plowed.

Where seed mixture 2 is used and hay cut for the first few years, arrange to graze the aftermath growth. Under favorable conditions this grazing should be a valuable summer supplement to other pasture land. If hay is not needed, this mixture may be grazed exclusively from time of seeding the same as Mixture 1.

[4] See discussion of grazing under Managing Permanent Pasture, page 434.

## 2. Improving the Non-Plowable Pasture

Many pastures are too rough and stony to be plowed. The herbage may have run out to such an extent that not only is the carrying capacity reduced to a low point, but also the surface soil has become subject to erosion. In some instances, the conditions are so unfavorable that improvement is impracticable. This is the result of clearing and pasturing areas that should have been left in timber. Such areas should be replaced by seeding down permanent pasture on better land, or by growing rotation pasture crops. If suited to grazing, such rough areas may be greatly improved by proper soil treatment and reseeding when necessary.

**Procedure:**

A. Examine the herbage and test the soil.
B. Apply superphosphate and, if needed, lime and potash.
C. Seed, if necessary.
D. Consider top-dressing with manure.

**A. Examine the herbage and test the soil.** The first thing to do in improving a pasture not suitable for plowing is to examine the herbage carefully. See how many white clover plants can be found. Even though there are but two or three to the square yard they may save the expense of seeding. The white clover plants persisting in old pastures are invariably the wild type and capable of spreading rapidly when the fertility of the soil and the grazing practices are made favorable for their growth. Next test the surface soil for acidity, and also note whether or not the desirable pasture grasses are present.

**B. Apply superphosphate and, if needed, lime and potash.** Apply superphosphate, rock phosphate, or basic slag at the rate of not less than 500 and preferably 800 pounds to the acre. Use a lime sower if the topography and surface condition will permit. Otherwise broadcast by hand. Where hand application becomes necessary, ammo-phos may be substituted.

Owing to its greater concentration (48 per cent phosphoric acid), only one-third as much need be applied. Ammo-phos is a granular product and may be applied by means of a knapsack, Cyclone fertilizer distributor or is readily applied broadcast by hand. For best results the first year, apply the phosphatic fertilizer in the fall. The fertilizer treatment should be repeated every three to five years.

FIG. 190. EXAMINING THE PASTURE SWARD.

The first thing to do in improving a pasture not suitable for plowing is to examine the herbage carefully. See how many white clover plants you can find.

If the soil test indicates acidity in excess of $p$H 5.5, or the lime requirement is found to exceed one ton of ground limestone for red clover, lime should be applied in addition to the fertilizer. Seldom will it be necessary to apply more than one ton of ground limestone to the acre. Apply the lime with a distributor, if possible.

Where soils are very poor and especially sandy or gravelly in character, potash may be needed. If needed, apply 100 pounds to the acre of muriate of potash or its equivalent.

Make the application in conjunction with the phosphatic material, and repeat the application at the same three- to five-year intervals. An 0–20–10 or 0–20–20 analysis of mixed fertilizer may be used to supply both phosphorus and potash. As the carrying capacity increases, the additional animal droppings will reduce the amount of fertilizer potash required.

**C. Seed, if necessary.** Where there is a good grass pasture sward containing as many as two or three well-distributed white clover plants to the square yard and the desired grasses are present, seeding should not be necessary. Under these conditions the fertilizer treatment outlined should stimulate the spreading of the clover, and in turn it will supply nitrogen for the grass. Many old pastures have been successfully improved by the application of 600 to 800 pounds of a phosphatic fertilizer material alone or accompanied by a ton application of ground limestone. Some soils require potash also.

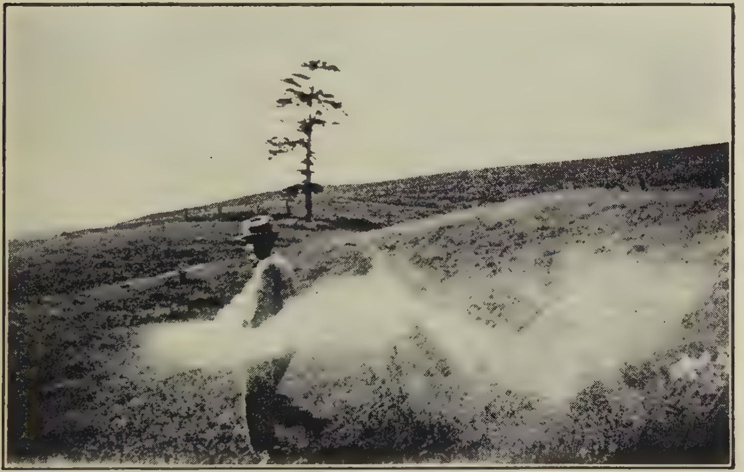

Fig. 191. Fertilizing Rough Pasture Land.

Ammo-phos is a granular product and may be applied by means of a knapsack, Cyclone fertilizer distributor or is readily broadcast by hand.

If there is little or no white clover in the pasture sward, then it will be necessary to add seed. Plan to do the seeding in the early spring in the North and in the central states, after the fertilizer has been applied. Harrow or disk the area to be seeded. Select a time when the moisture content of the soil is such that the operation will be effective. Go over the land two or three times in order to loosen it up so the seed will catch. In the South seed, including white clover, may be planted to advantage in the fall.

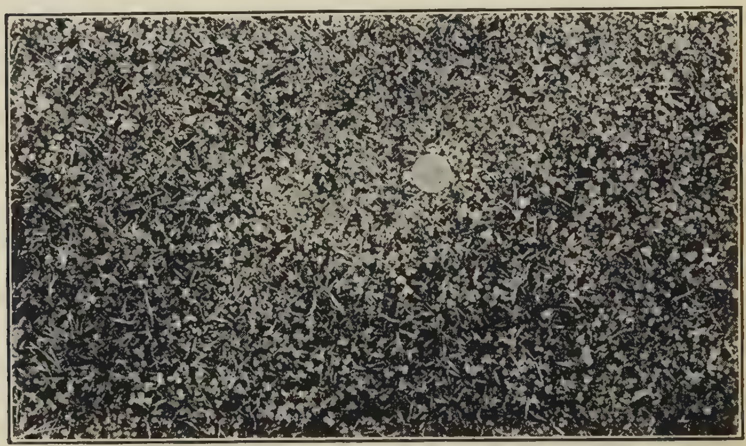

Fig. 192. An Excellent White Clover Bluegrass Sward.

Where there is a good grass pasture sward containing as many as two or three white clover plants to the square yard, the fertilizer treatment outlined should stimulate the spreading of the clover, and it in turn will supply nitrogen for the grass.

The seeding may consist of a mixture or it may be white clover alone. For the whole northeastern section of the country except on very sandy land it should contain at least some white clover, either the wild white or the Ladino white clover. Where the winters are less severe, the white Dutch type may be used. If a mixture is used, seed at the rate of 12 pounds or more to the acre. If the herbage has been found to contain desirable pasture grasses, such as bluegrass, bent grass, or fescue in the north-central and eastern states, or carpet grass, Bermuda or Dallas grass in the South, harrow over lightly and seed white clover alone at the rate of one pound to the acre. In order to distribute such a light rate of seeding uniformly it will be necessary to mix it with sand, ground limestone, or superphosphate. In some sections, other legumes such as hop clover, Persian clover and Lespedeza may replace or be seeded in addition to white clover.

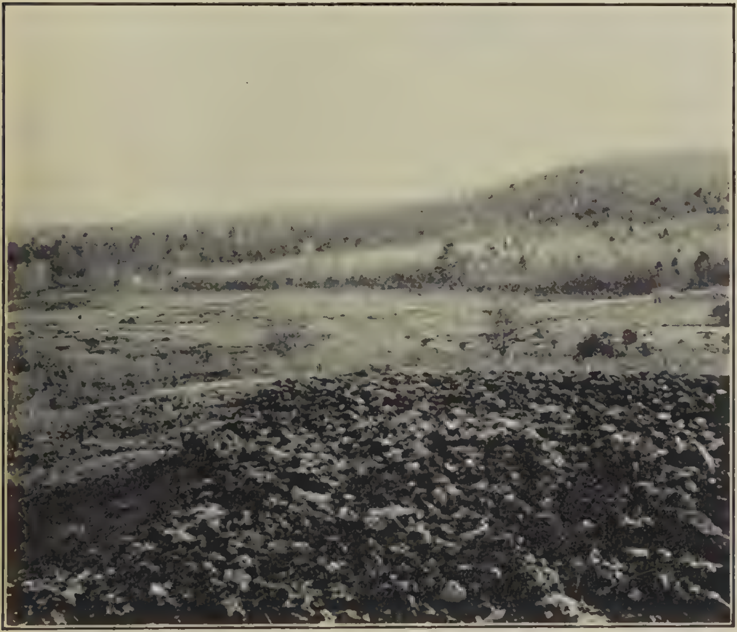

FIG. 193. PASTURE SEED-BED PREPARED BY HARROWING.

If the pasture is non-plowable, harrow or disk the area to be seeded.

The seeding of sweet clover on old pastures has been extensively advocated. Only under favorable conditions will this legume grow when seeded on pasture sods. Where the soil and subsoil are well supplied with lime, a successful catch of sweet clover may be secured on permanent pastures, but some soil preparation will generally be required. Such a soil condition practically never occurs in old, run-out pastures.

In the improvement of non-plowable permanent pastures, it is best to proceed with a section of the pasture each year. This will allow for fencing the treated area so that the grazing can be regulated for one or two seasons. During the first year of treatment, graze the area lightly. Give the grass a chance to become thoroughly reestablished, but do not permit it to crowd and shade the clover. Disappointment invariably follows when pasture improvement is attempted without giving supervision to the grazing of the treated area.

**D. Consider top-dressing with manure.** Farm manure can be used to advantage in the improvement of run-out permanent pastures. Unfortunately, many of these pastures are so rough and stony or so far from the barn that it is impracticable to get manure on them. In general it has been found, however, that manure can be used to better advantage on rotation crops than on pastures. The application of manure where white clover predominates in the herbage is seldom the best use of it. It is in connection with the improvement of the depleted grass pastures that manure can be used most advantageously. However, sheep manure should not be applied to pastures grazed by sheep, as it fosters parasitic diseases.

In applying manure to pastures, superphosphate or some other phosphatic fertilizer material should be applied in addition. It should never be applied alone except on pastures which have recently received a phosphatic fertilizer material. From the standpoint of economy, superphosphated manure should be used to avoid the expense of a separate application of the fertilizer and the manure.

Where seedings are made on old pastures, manure may be used to advantage since it discourages grazing for several months, thus protecting the new seeding without the expense of fencing. If the supply is limited, use it on the poorer areas that are to be improved and depend on superphosphate or other phosphatic material, either with or without lime, on the better parts of the pasture. Poultry or sheep manure will discourage grazing by cows less than will cow manure.

The rate of application of superphosphated manure should be 6 to 10 tons to the acre. Distribute with a spreader if possible. Apply at any season to a depleted pasture, preferably in conjunction with or previous to the seeding of a pasture mixture.

### 3. MANAGING PERMANENT PASTURES

Where permanent pastures have been successfully improved or where they are naturally in good condition, manage them properly in order to keep them productive. It is a mistaken idea that a permanent pasture occasionally needs to be plowed and reseeded. Some of our best pastures have been in continuous sod for fifty to a hundred years. A good pasture can be made better and its carrying capacity maintained indefinitely by good management practices including adequate fertilization.

**Procedure:**

A. Fertilize and, when needed, apply lime.
B. Regulate grazing.
C. Clip weeds and ungrazed herbage.
D. Scatter droppings.

**A. Fertilize and, when needed, apply lime.** A high fertility level of the soil must be maintained to insure the permanency of a good pasture. Practically all the pasture soils of the eastern half of the United States are deficient in phosphorus and nitrogen; many of them are too acid for bluegrass and clover, and some are lacking in available potash. The first essential in their fertilization is the supplying of adequate phosphorus. This requires an application of 500 to 800 pounds to the acre of superphosphate, basic slag, or rock phosphate every three to five years. The application should be made in either the early spring or late fall, preferably in the fall. It is not necessary to treat the whole pasture any one year. The expense may be distributed over a three- to five-year period. Where the application is at the rate of 800 pounds to the acre, fertilize one-fourth to one-fifth of the pasture each year; and where it is a 500- to 600-pound rate, apply to one third of the pasture each year. Many pastures well supplied with white clover will require no additional fertilization. Some, especially those on sandy soil, may need potash in addition to phosphorus. Where potash is found to be needed, apply as specified for the improvement of non-plowable pastures.

In order to make this relatively inexpensive system of fertilization effective, it is necessary to have white clover or some other legume in the pasture sward. Nitrogen must be supplied either by legumes, manure, or fertilizer. When conditions are made favorable the legumes are capable of supplying adequate nitrogen for the grass. The leguming of land has been found just as practical with pastures as with field-crop rotations. Of the pasture legumes, the white clovers are adapted to the greatest diversity of conditions. Lespedeza, trefoil, hop clover, and burr clover are other good pasture legumes, but they are more restricted in their adaptation.

Legumes are desirable in permanent pastures not only because they supply an inexpensive source of nitrogen, but also because of their high feeding value. In addition to being high in protein they are rich in such minerals as calcium and phosphorus. Their presence in the pasture herbage invariably improves its feeding value, and its palatability as well.

So long as white clover thrives in the permanent pasture, lime need not be applied. White clover and the other permanent pasture legumes will grow on acid soil if adequate amounts of minerals, particularly phosphorus, are supplied. If at any time the white clover becomes reduced either in growth or stand, test the soil, and if it is found to be distinctly acid, apply lime. To be best suited to white clover, the soil should test from $p$H 6 to $p$H 7. At any time that the acidity becomes as great as $p$H 5.5, apply lime at the rate of a ton of ground limestone to the acre.

Though manure may often be used to advantage in the improvement of poor pastures, it should not be applied to good-quality bluegrass-white clover pastures. Owing to the high nitrogen content, it stimulates the growth of grass and weeds which tend to shade and crowd the clover. This condition is intensified by the refusal of animals to graze freshly manured herbage. Though less objectionable than manure, fertilizer nitrogen applied to the pasture may stimulate the grass at the expense of the clover. This invariably happens unless the pasture is closely grazed. Unlike manure, fertilizer results in better grazing.

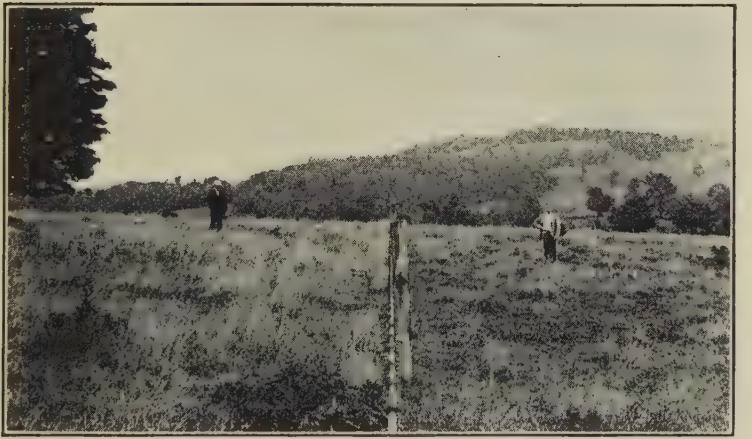

FIG. 194. FERTILIZER ENCOURAGES GRAZING.

**Unfertilized pasture on left. Pasture fertilized with ammo-phos on right. Unlike manure, fertilizer results in better grazing.**

With the legume-mineral method of pasture fertilization, a carrying capacity of one cow or its equivalent to the acre may be maintained thoughout much of the season. To secure the maximum carrying capacity it becomes necessary to make liberal applications of nitrogenous fertilizer. Although more expensive than the mineral-legume method, the complete fertilizer-nitrogen treatment may be justified in intensive dairy farming where the area of pasture is restricted and where whole milk is sold directly to the city consumer, or otherwise commands a better than average wholesale price.

In the intensive system apply superphosphate and, when needed, lime and potash the same as in the legume-mineral method. In the early spring apply 200 pounds of nitrate of soda or sulfate of ammonia to the acre to the pasture area which is to be used for early grazing. Additional applications of 100 pounds of the nitrogenous material should be made at intervals during the summer when pasture areas have been grazed down and the animals removed to ungrazed areas. If desired an annual early spring application of 300 pounds to the acre of a mixed fertilizer such as the 10–10–10 may replace the superphosphate, potash, and spring application of nitrogenous fertilizer. The intensive system necessitates division of the pasture into four to six lots, each provided with water, and the employment of good grazing practices.

**B. Regulate grazing.** Good grazing management is essential to success with permanent pastures. It encourages the production of palatable herbage of high feeding value, and maintains so far as possible good pasturage throughout the season. Animals prefer the young, tender leaves which are not only more palatable but also much more nutritious than the stems and mature leaves. The young leaf growth of a bluegrass-white clover pasture contains up to 30 per cent protein in the dry matter, whereas the mature herbage on grass pastures seldom contains as much as 10 per cent and sometimes not over 6 per cent. The aim in grazing management should be to furnish an adequate supply of young, succulent herbage throughout the grazing season.

In planning the grazing management one should appreciate that pastures may be injured by either undergrazing or overgrazing. When continuous grazing is practiced there may be both overgrazing and undergrazing in the same pasture. The animals start grazing where the herbage suits them best, leaving areas of less desirable herbage ungrazed in the spring. The grass in the ungrazed areas may reach a stage of maturity so that it is not relished by the animals and as a result remains ungrazed throughout the season. Overgrazing or continuous grazing weakens the sward because the plants are not permitted to make sufficient top growth to reestablish a root reserve of plant-food. Overgrazing should be guarded against if the fertility level of the pasture soil is low, if the climate is dry, and if the herbage contains few legumes. On the other hand, pastures on rich moist soils, or those in which white

FIG. 195. A WELL-GRAZED PASTURE.

The aim in grazing management should be to furnish an adequate supply of young, succulent herbage throughout the grazing season.

clover or other legumes are present, or those that are fertilized with nitrogen, are frequently undergrazed.

Efficient grazing requires what is known as alternate or rotation grazing. Consequently on many farms the first thing to be done is to subdivide the permanent pasture into several lots, each having a water supply, or each connected with a central paddock supplied with water. Arrange to graze these different pastures alternately, turning all animals onto one pasture until it is grazed down closely and then changing to a new pasture. On dairy farms permit the milking animals to graze first, and when they are removed to a new pasture turn in the young and dry stock or other farm animals to complete the grazing of the given area. Remember that when a pasture is grazed it should be grazed closely. It is not close grazing but continuous close grazing that normally causes injury.

FIG. 196. AN UNDERGRAZED PASTURE.

Pastures are frequently undergrazed. The grass may reach a stage of maturity so that it is not relished by the animals, and as a result remains ungrazed throughout the season.

Good pastures may be grazed early without serious injury. Undue emphasis has been placed on the injury of early spring grazing. Although precaution should be taken to prevent damaging the sward by grazing while the soil is wet, the animals should be turned out early enough to utilize the succulent spring growth. If there are several pastures, start grazing the first one when the herbage reaches a height of 3 inches. Stock the pasture heavily so the herbage will be grazed off within a week. Then give it a rest period of two to three weeks. So far as possible, turn the animals onto pasture other than the first one when the herbage reaches a height of 4 inches. When necessary to prevent undergrazing, mow one of the pastures during the flush spring season. The herbage will make good-quality hay, or it may be utilized as grass silage. If there are several pasture lots choose a different one each year for the first grazing in the spring. By so doing, any possible injury resulting from early grazing will be distributed over all of them. In planning the grazing practice, remember that there is less danger of overgrazing a good pasture than a poor one, and that, if there is a large proportion of white clover in the herbage or if the pasture is liberally treated with nitrogenous fertilizers, there is more danger of undergrazing than of overgrazing. If the clover is the Ladino white, the grazing should be less severe.

The grazing management of range pastures is an entirely different problem. Such pastures are largely confined to regions of low rainfall. They consist of the native grasses without legumes, and have seldom received any special soil treatment. Their carrying capacity is dependent on the amount of rainfall rather than on the fertilizer level of the soil. In their management, above all else, avoid overstocking and premature grazing in the spring. Watch the condition of the vegetation from year to year and reduce the number of animals if the grass shows any indication of regression. Prevent injury due to the herding together of animals in special areas. This can be accomplished by furnishing well-distributed watering and salting places.

The carrying capacity of pastures varies to such an extent that no rule can be given as to the area required for each animal. From 2 to 5 acres of the better grade of permanent pastures are required for a mature cow or its equivalent. Especially good pastures will carry a cow to the acre during the late spring and early fall, but many are so poor that 8 to 10 acres are needed for each animal unit. Range pastures have a lower carrying capacity than the regular farm pastures of the central and eastern states. A range pasture is considered good if it will support a cow to 5 acres. Often 10 and even

FIG. 197. A RANGE PASTURE IN MONTANA.

In the management of range pastures, above all else, avoid overstocking and premature grazing in the spring.

20 acres are required per livestock unit. Consequently, the regulation of the number of animals which can be grazed advantageously is a matter of experience and judgment. Watch the condition of the vegetation, and adjust the grazing practice to the type and condition of the pasture.

**C. Clip weeds and ungrazed herbage.** In the improvement of old permanent pastures one to three mowings a year may be necessary in the beginning to kill weeds and brush growth. On pasture land that has been long neglected it may be necessary to cut or grub out the larger brush and the tree growth. Even improved pastures require clipping to encourage uniform grazing. Invariably there will be poorly grazed areas when animals are transferred to a new pasture. All ungrazed herbage should be cut prior to the removal of the animals to assure their being grazed uniformly later in the season. The object of mowing a day or two before removing animals, is to give them an opportunity of eating the clippings which they normally will do. In mowing pastures, always cut the herbage as closely as possible. Clipping is most often necessary on dairy farms and may be lessened by turning dry and young stock, horses or sheep onto the pasture for a short period after the milking animals have been removed.

**D. Scatter droppings.** In the management of improved pastures which have a carrying capacity of a cow to one or two acres, the animal droppings should be scattered at least once a year. In very intensive systems of management they should be scattered whenever the animals are changed to a new pasture. Harrowing prevents the development of ungrazed herbage and weeds around the unscattered droppings and, as a result of distributing the droppings, their fertilizing value is increased. The flexible grass or pasture harrow is the best implement for scattering the droppings. If this type is not available, use a smoothing or a spring-tooth harrow.

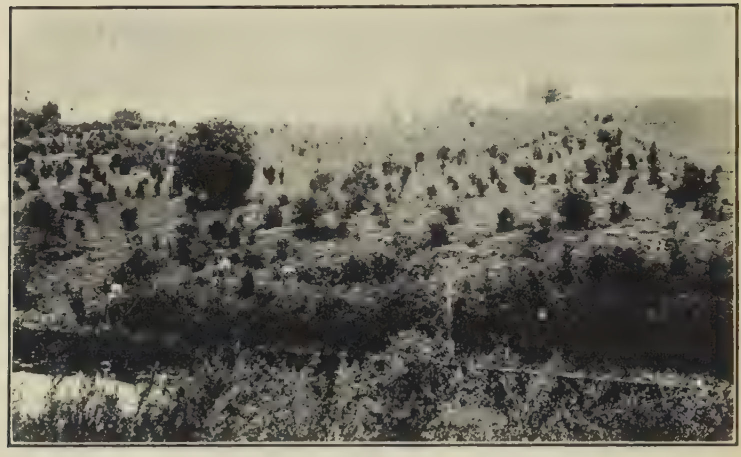

FIG. 198. A NEGLECTED PASTURE OVERRUN WITH TREES AND BRUSH.

On pasture land that has been long neglected it may be necessary to cut or grub out the larger brush and tree growth.

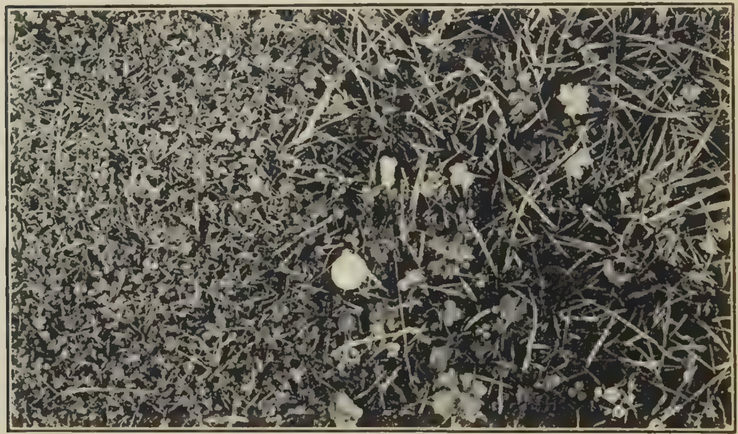

FIG. 199. UNGRAZED HERBAGE ON RIGHT CAUSED BY AN ANIMAL DROPPING.

The ungrazed herbage and weeds to the right in the photograph are the result of an unscattered animal dropping.

Harrowing prevents the development of ungrazed herbage and weeds around the unscattered droppings.

## 4. Incorporating Pasture in the Rotation

A rotation pasture system may be established either by pasturing one or more of the regular rotation crops or by incorporating a special pasture crop in the regular field-crop rotation. On most farms the former practice is followed to a greater or less extent. Where fields are fenced, stock is usually turned on corn and small-grain fields after harvest. It is a common practice in livestock sections to pasture hay land in the late summer and early fall. Sometimes the new seeding is pastured in the fall, but this is seldom advisable. However, these practices do not constitute a real rotation pasture system. Such a system results when the meadow, after being cut for hay for one or two seasons, is utilized exclusively for pasture for a year or more. Also, by seeding a crop such as sweet clover or Sudan grass in the rotation with the avowed purpose of using it exclusively for grazing, a true rotation pasture system is developed.

Rotation pastures are best suited to farms that consist largely of tillable land which is adapted to general field-crop production. They are valuable on many farms for supplementing the permanent pastures during July and August.

**Procedure:**

A. Pasture meadows.
B. Grow special pasture crops in the rotation.

**A. Pasture meadows.** The most common rotation pasture practice is to graze meadow land for one or two years following hay production. This necessitates a long rotation, for land must be kept in grass for at least three years, and preferably for four or five. Instead of a definite area's being set aside for pasture purposes, the pasture enters the rotation, and over a period of years will have occupied all fields of the farm; thus the productive capacity of the whole farm will be enhanced as a result of all the fields' receiving the beneficial effect of pasturing.

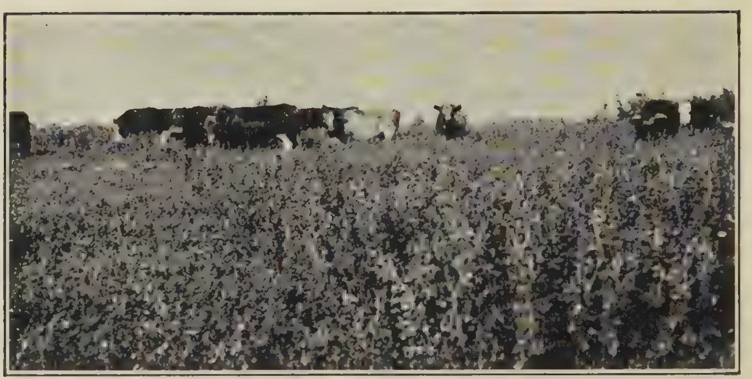

FIG. 200. A SWEET CLOVER ROTATION PASTURE.

By seeding a crop such as sweet clover or Sudan grass in the rotation with the avowed purpose of using it exclusively for grazing, a true rotation pasture system is developed.

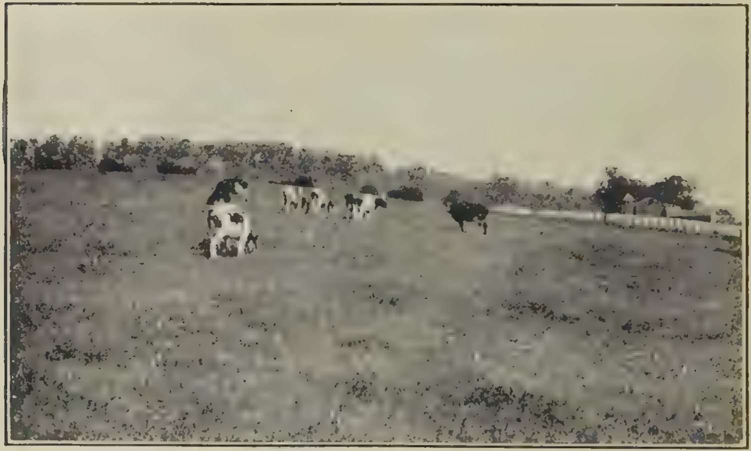

FIG. 201. PASTURING CLOVER AND TIMOTHY MEADOW.

The most common rotation pasture practice is to graze meadow land for one or two years following hay production.

Where the meadow seeding consists of timothy and clover, seed a pasture mixture in addition. Unless this is done, the pasture will consist largely of timothy, or timothy and weeds, as the clover will have largely run out by the end of the second year of hay. In addition to clover and timothy, seed either alfalfa or Ladino clover or both. Some redtop and bluegrass can be justified in most cases. Especially adapted for the purpose is pasture Mixture 2 on page 422.

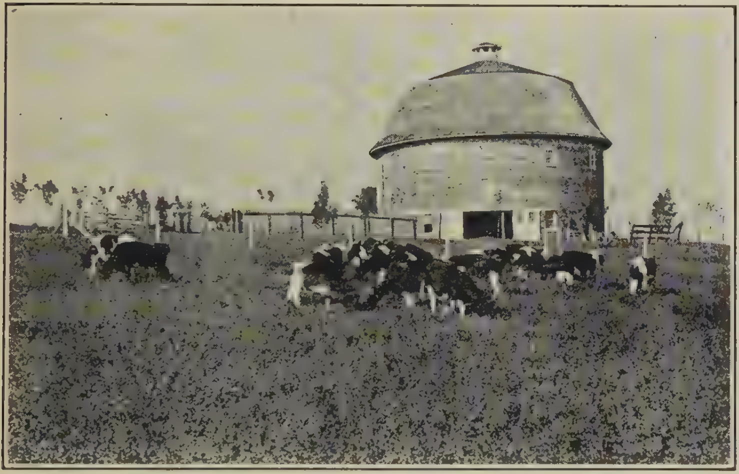

FIG. 202. PASTURING ALFALFA. (Dairy Hus. Dept., Ill. Agr. Exp. Sta.)

Alfalfa is recognized as a most valuable pasture crop, though precaution must be taken in grazing it to prevent the bloating of animals.

When alfalfa constitutes the hay crop of the rotation, it can be utilized in the same way as a pasture crop. Pasture grasses need not be seeded with it, but one should exercise precaution not to overgraze, and to remove stock in the fall to permit a growth of several inches prior to winter. However, when the hay is to be fed on the farm, and especially when grazing is to be practiced, it is better to replace clear alfalfa with a mixture which includes this legume. Alfalfa is recognized as a most valuable pasture crop, though precaution must be taken in grazing it to prevent the bloating of animals.

When the rotation is thus lengthened to include two years of pasture, it becomes necessary to increase the lime and fertilizer treatments applied to the grain crops, in order to secure an adequate residual effect for both hay and pasture. If this is not done, apply 200 to 300 pounds to the acre of superphosphate to the first-year pasture, whether it be timothy sod or alfalfa. If available, apply manure during the fall or winter preceding the grazing period, unless there is a good proportion of alfalfa or Ladino clover in the sward.

Another use which should more often be made of meadows is to graze the aftermath or second growth. Used in this way they furnish a most valuable supplement to the permanent pasture since the aftermath supplies grazing at the season when the permanent pasture has a reduced carrying capacity. In order to secure good aftermath grazing, include 6 to 8 pounds of alfalfa to the acre with the seeding mixture for land suited to this legume, and on land not suited to it add 6 to 10 pounds of Kentucky bluegrass and 1 to 2 pounds of Ladino clover to the seed mixture for each acre. Pasture Mixture 2 is as well suited for this purpose as for exclusive grazing.

**B. Grow special pasture crops in the rotation.** Special crops, such as sweet clover, can often be grown in the rotation and used advantageously for pasture. The soil should be well supplied with lime, and inoculation must be provided unless sweet clover or alfalfa has been grown successfully on the field previously. Seed either alone or with fall or spring grain as a companion crop. When seeded alone, much better grazing will be secured the first year. Seed in May or early June on a well-prepared seed bed. Use scarified seed when the seeding is made with the spring grain. When sweet clover is started with winter grain, seed it in the late fall, during the winter, or in the very early spring. Make the fall seeding late enough to keep the seed from germinating before spring.

Seed at the rate of 15 to 18 pounds of the unscarified hulled seed, or its equivalent of unhulled seed, to the acre. Either the yellow- or white-blossom, biennial type should be used. Where the soil is adequately supplied with lime, no special treatment is needed for sweet clover. Give the grain crops in the rotation enough superphosphate and when needed, potash as well, so the residual effect will carry over for the sweet clover.

Fig. 203. A Sweet Clover Sheep Pasture.

Special crops such as sweet clover can often be grown in the rotation and used advantageously for pasture.

In favorable seasons the sweet clover can be pastured during the fall of the first year, even where seeded with a companion crop. However, it is not until the second season that the crop reaches its maximum carrying capacity. From early spring until late summer of the second year, a good sweet-clover pasture will carry a cow or more to the acre. Turn animals onto sweet clover early in the spring of the second year. Graze heavily, and do not let the crop reach a height of more than 8 to 10 inches or it will form seed and die. If soil conditions are favorable and the crop is properly grazed, it will furnish nutritious, high-protein feed during the one summer, and at the same time it will leave the soil well supplied with available nitrogen for the grain or silage crop which would normally follow in the rotation.

Success has seldom followed attempts to secure permanent sweet-clover pastures. Sweet clover is primarily a two-year crop and should be so considered when used for pasture. It is not satisfactory for supplementing permanent pastures since its maximum carrying capacity the second year comes at the same time as that of the permanent pasture. It may itself be supplemented to advantage in late summer and fall by the grazing of meadow aftermaths.

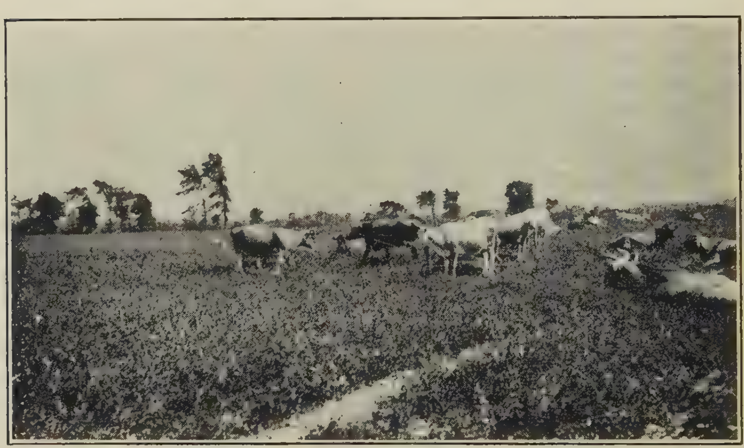

Fig. 204. Sweet Clover Pasture in Late August.

From early spring until late summer of the second year, a good sweet-clover pasture will carry a cow or more to the acre.

### 5. Growing Annual Pasture Crops

Annual pasture crops are those that are seeded annually and pastured for the one season only. In some instances, two separate crops are grown for pasture on the same land in a single season. These temporary pastures are used most extensively for hogs and sheep. As emergency pastures during years when the regular pasture is being improved, or when for some other reason there is a temporary pasture shortage on the farm, the annual pasture can be justified for cattle.

For this type of pasture, consider such crops as rape, rye, oats, soybeans, millet, Sudan grass, and sorghum. In the South include cowpeas, burr clover, velvet beans, and vetch in the list.

Fig. 205. Temporary Hog Pasture of Rye. (Animal Hus. Dept., Ill. Agr. Exp. Sta.)

For temporary pasture, select fertile soil, and seed at a somewhat heavier rate than is normally used in field-crop production.

For temporary pasture, select fertile soil, and seed at a somewhat heavier rate than is normally used in field-crop production. Unless the soil is in a high state of productivity, fertilize liberally with superphosphate and apply manure in addition. If the soil is acid, apply lime, in amounts to satisfy the lime requirement of the crop to be grown. Consult your state college of agriculture or your local county agricultural agent before deciding on the best temporary pasture crops for your local conditions.

## GENERAL INFORMATION

### 1. Pasture Areas of the United States and Character of Vegetation in Each

The character of the pasture vegetation varies in different sections of the country. The type of pasture vegetation and the proportion of the different plants constituting the pasture herbage depend primarily on climate and soil. There are five important pasture areas in the United States. These are shown in Fig. 206. The northern two-thirds of the country is better suited to permanent pastures than the southern one-third, and the best pastures are found in Section 1.

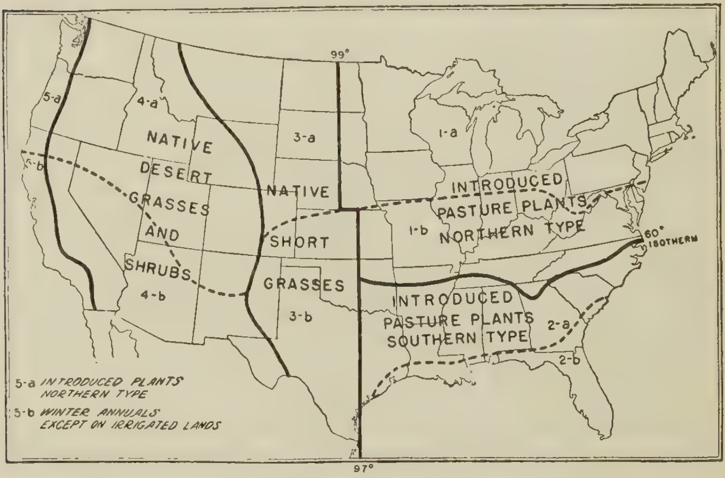

Fig. 206. Pasture Areas of the United States. (U. S. Dept. of Agr. Miscel. Publication 194.)

The more important plants in permanent pastures in Section 1 are: Kentucky and Canada bluegrass, timothy, orchard grass, bent grasses, fescues, and the white clovers. The three types of white clovers used in pastures are (1) the common white Dutch, (2) the large Ladino white, and (3) the small wild white. In Section 2 the important plants are: Bermuda grass, Johnson grass, carpet grass, Dallas grass, white clover, trefoil, hop clover, and Lespedeza. In Sections 3 and 4 the pastures consist of ranges of native prairie grasses. In Section 3, the herbage consists largely of the so-called "short grasses" such as the gramas, buffalo and mesquite grasses; in Section 4, bunch grasses and desert shrubs dominate in the ranges. In the northern part of Section 5 perennial rye grass is of importance. Otherwise the pasture herbage is similar to that in Section 1. In the southern part of Section 5 winter annuals become important in the permanent pasture, and on irrigated land alfalfa is extensively grazed.[5]

## COMMUNITY STUDIES

1. Visit several permanent pastures in the community. Examine the vegetation and determine the amount of white clover in the pasture. As far as possible, identify the grasses and weeds present.
2. Do you consider the pasture well grazed? To what extent are there areas of ungrazed herbage? Determine why the animals have failed to graze these areas.
3. Secure information as to the carrying capacity of the pastures examined.
4. To what extent does the carrying capacity vary during the grazing season?
5. Are the permanent pastures of the community fertilized? If so, what fertilizer is applied, and when?
6. Do farmers apply lime or manure to their permanent pastures?
7. Are any of the pastures divided so that alternate grazing can be practiced?
8. Is it a common practice to plow and reseed the permanent pasture? If so, determine what seeding mixture is used.
9. Do any farmers clip the ungrazed herbage and weeds?
10. Do any of them scatter the animal droppings?
11. Outline a system of fertilization and management which, in your estimation, would result in the improvement of the average permanent pasture in your neighborhood.

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[5] For character of pasture grasses, see "Crop Production and Soil Management," by Cox, published by John Wiley & Sons.

12. To what extent are meadows grazed? Is it a good practice for your section?

13. Do any farmers seed special pasture crops on rotation land? If so, what crops do they seed?

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Seeding and Management of Nebraska Pastures. Neb. Ext. Cir. 138.

## CHAPTER XI

# MANAGING GARDEN, GREENHOUSE, AND LAWN SOILS

A well-drained loam or sandy-loam soil is best suited for vegetables and flowers whether grown in the home garden or produced commercially by the market gardener. When such soils are properly treated, vegetables and flowers can be produced successfully year after year. For the lawn, however, a heavier soil is desirable. A loam, silt loam, or clay loam is particularly well suited to the lawn grasses. On soils of this character a good lawn, free from weeds, can be established and, with proper treatment, maintained indefinitely.[1]

Failure to secure satisfactory results in either the home vegetable or flower garden or the lawn is due more often to excessive than to inadequate soil treatment. Lime, as well as wood ashes, has frequently been applied in excessive amounts. Manure has often been used without fertilizer on the home garden, resulting in an excess of nitrogen which causes vegetables to "go to tops" and flowers to produce excess foliage at the expense of bloom. Lawn and garden soils, properly manured and fertilized, will not only remain productive but will even improve from season to season. Special attention is required to secure good soil for the greenhouse and to maintain it in good condition.

**Operations:**

1. Tilling the garden.
2. Fertilizing the vegetable garden.
3. Fertilizing flowers.
4. Preparing and fertilizing greenhouse soils.
5. Fertilizing the lawn.

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[1] See Chapter I for soil texture and classification.

### 1. Tilling the Garden

Till garden soils thoroughly. This includes not only the preparation of a good seed-bed but also the adequate cultivation of the growing crops. Neglect in tillage will prevent the fertilizer treatment from producing its full effect. Fortunately, the net returns from intensive vegetable or flower production are sufficient to justify any reasonable expenditures for tillage operations.[2]

Fig. 207. A Home Vegetable Garden. (Hort. Dept., Ill. Agr. Exp. Sta.)

On properly treated, well-drained loams or sandy loams, vegetables and flowers can be produced successfully year after year.

**Procedure:**

A. Plow early and deep.
B. Plow under organic matter.
C. Prepare a good seed-bed.
D. Cultivate thoroughly.
E. Grow green-manure crops.
F. Rotate crops.

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[2] See Chapter IV for soil tillage.

**A. Plow early and deep.** Plow or spade the garden in the fall or early spring. Where cover crops are not seeded, plow in the fall. Fall plowing is particularly desirable if the soil is heavy in character, as it will make possible earlier seed-bed preparation in the spring. Even where winter cover crops are grown, plowing may be necessary in preparing the soil for their seeding, though this can generally be accomplished more economically by disking. Where the plowing is not done in the fall, or where winter cover crops are grown, plow early in the spring. Do not permit the cover crop to make a rank spring growth before plowing it under.

Plow or spade garden soils to a depth of 7 to 9 inches. If the surface soil is less than 9 inches in depth and shallow plowing has been practiced in past years, increase the depth gradually so as not to throw large quantities of subsoil to the surface in any one season.

**B. Plow under organic matter.** Garden soils must be kept in good physical condition. This necessitates a high organic-matter content. Because of the continuous production of cultivated crops, the organic matter decomposes rapidly, necessitating the return of large amounts in order to maintain a satisfactory supply.

Farm manure, if available, is an excellent source of organic matter for garden soils. Either horse or cow manure may be used. A mixture of the two is to be preferred to either alone. Select manure that is free from weed seed and use rotted manure in preference to fresh manure. Apply broadcast prior to plowing at the rate of 12 to 20 tons to the acre and plow into the soil. If available, poultry manure may be substituted at the rate of 20 to 25 pounds to the hundred square feet. Best results will be secured if the manure is applied and plowed under in the fall.[3]

All weeds and discarded parts of vegetables, unless diseased, should be thrown into a pile to rot, and the resulting compost distributed over the garden prior to plowing.[4] Green manure is a third possible source of organic matter for either the home garden or the commercial market garden.

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[3] See Chapter V for manuring the soil.

**C. Prepare a good seed-bed.** Prepare a good seed-bed for the garden crops. This is often difficult to do in the home garden because of the lack of proper tools. The hand rake is ordinarily inadequate for the purpose. In small gardens which are spaded, the soil can be so well broken up during the operation that the hand rake will suffice for seed-bed preparation. However, where the garden is plowed, prepare the seed-bed by first disking and then harrowing several times with a smoothing harrow prior to the use of the hand rake. If the soil is heavy, a roller or drag can be used to advantage

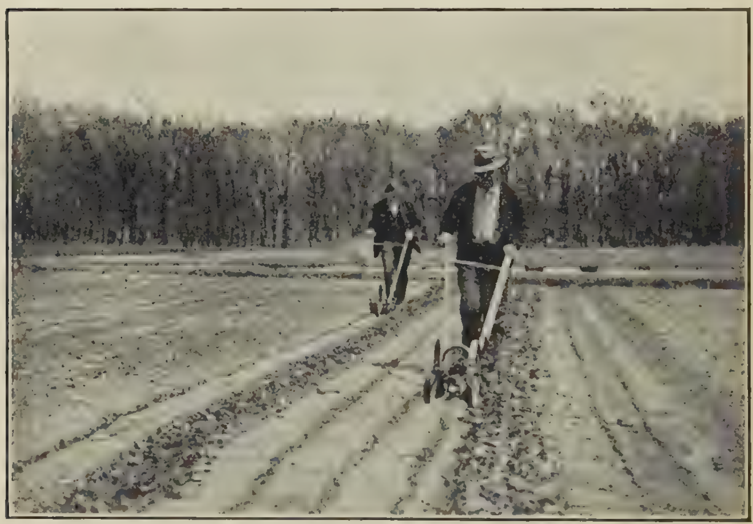

FIG. 208. CULTIVATING VEGETABLES WITH A HAND CULTIVATOR.

Give the garden thorough cultivation throughout the growing season. In the small home garden use the hand cultivator.

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[4] See Chapter VIII for information on making artificial manure.

in breaking clods. Aim to produce a uniformly mellow seed-bed with a depth of at least 7 and, better still, 8 or 9 inches.[5]

**D. Cultivate thoroughly.** Give the garden thorough cultivation throughout the growing season. Above all else, do not let the weeds get a start. In the small home garden, use the hand cultivator. In the larger farm garden, make use of the one-horse cultivator; in commercial gardening, use either a horse or a power-driven cultivator. The cultivation should be level and shallow, and only frequent enough to keep the weeds from getting a start. Pull or hoe weeds from the rows before they become large enough to crowd the vegetables.

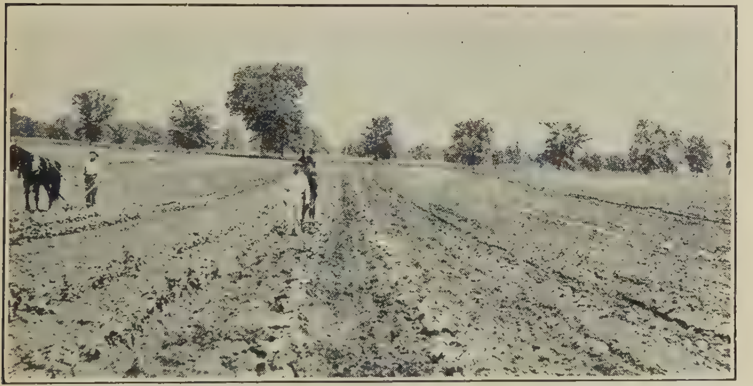

FIG. 209. CULTIVATING VEGETABLES WITH A HORSE CULTIVATOR. (Hort. Dept., Ill. Agr. Exp. Sta.)

In the farm vegetable garden make use of the one-horse cultivator.

Frequently the home vegetable garden is given adequate cultivation early in the season, and neglected in the late summer and fall. As a result, weeds make a rank growth, and often mature seed. Give the garden a thorough cultivation once every ten days or two weeks throughout the growing season.[6]

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[5] See Chapter IV for seed-bed preparation.

[6] See Chapter IV for crop cultivation.

**E. Grow green-manure crops.** Plan to grow green-manure crops in the garden if no manure is available. On most farms there is plenty of manure for the kitchen garden. The market gardener who is dependent on the city as a source of manure is finding the supply inadequate and the price high. As a result, he is depending more and more on green-manure crops in replenishing soil organic matter.

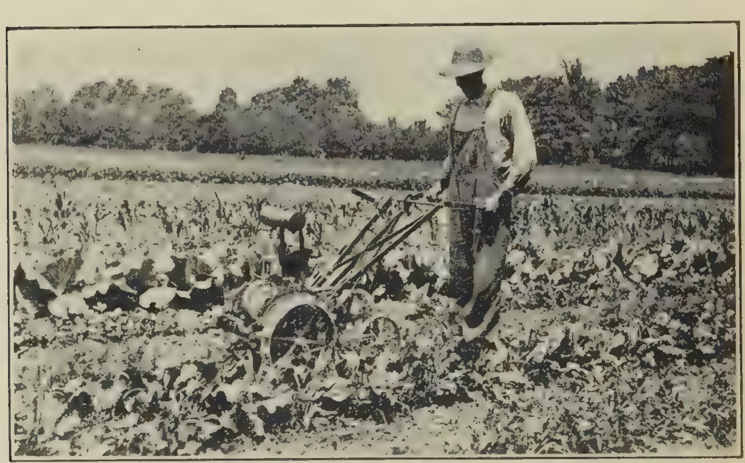

FIG. 210. CULTIVATING VEGETABLES WITH A POWER-DRIVEN CULTIVATOR. (Hort. Dept., Ill. Agr. Exp. Sta.)

In commercial gardening use either a horse- or a power-driven cultivator.

There are two possibilities in the seeding of green-manure crops in the garden: they can be seeded between the rows (1) at the time of the last cultivation, or (2) immediately after the crop has been harvested. The latter method is generally preferable, though it necessitates disking or harrowing the soil after the vegetable crop is removed. Choose some one of the standard green-manure crops, and seed at the proper rate and at the proper time. Plow under either in the late fall or in the early spring. Where the soil is sandy, and particularly in the South, leave the crop as a winter cover. In the North, however, where early vegetables are to be grown, plow the green manure down in the fall.[7]

**F. Rotate crops.** Garden crops, like field crops, should be grown in rotation. A proper rotation has been found to aid in the control of certain common diseases where the germs live over winter in the soil. For example, early blight and fusarium wilt, as well as scab of potatoes, are known to carry over the winter in the soil or on the crop residues. Club root of cabbage and wilt and blight of tomatoes are other diseases which are carried over in the soil. Greenhouse soils may be sterilized by steaming, but there is no practical means of destroying injurious organisms in garden soils. By rotating the crops, injury at least can be greatly reduced.

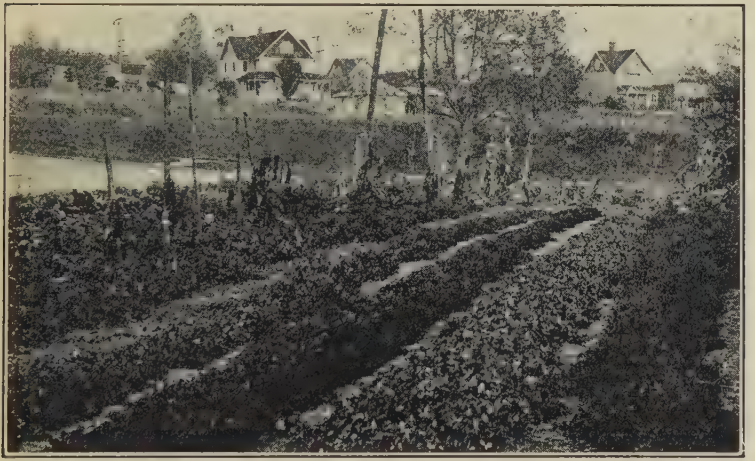

FIG. 211. A GREEN-MANURE CROP IN VEGETABLE GARDEN.

Plan to grow green-manure crops in the garden if no manure is available.

A somewhat definite sequence of crops should be followed by the market gardener. Avoid growing the same vegetable, or in fact the same type of vegetable, in the same location in successive years. In the home vegetable garden, all that may be necessary is shifting the location of the different vegetables each year. However, where space permits, half the garden area should be seeded to a sod crop in alternate years and plowed under in the fall, then followed by vegetables the next year.

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[7] See Chapter VIII for the production of green-manure crops and cover crops.

### 2. Fertilizing the Vegetable Garden

Fertilize garden soils liberally. Many vegetable crops have a relatively short growing season and, in addition, a restricted root system. It is essential that they make a rapid growth in order that they be of the best quality. By means of proper fertilization, the date of maturity can be advanced several days, which is very desirable, especially with early vegetables. Fertilizer will not replace good tillage or an adequate supply of organic matter in the form of farm manure or green manure, but it must be applied in addition to them for best returns from the garden.

The commercial producer must also supply liberal fertilization for vegetables. He is following an intensive system of production on relatively high-priced land. Consequently, good yields must be secured. In addition, a product of good quality and of attractive appearance is essential for successful marketing. The date of maturity is also an important item, since better prices are almost always secured for vegetables marketed prior to the flood season. Growers use the term *beating the market* to express the importance of early maturity. They have found that the use of commercial fertilizers enables them to produce more and better-quality vegetables and to mature them at an earlier date.[8]

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[8] See Chapter VII for purchasing, applying, and home-mixing fertilizers.

**Procedure:**

A. Use complete fertilizer.
B. Choose the proper analysis.
C. Select a good formula.
D. Apply properly.
E. Apply lime when needed.

**A. Use complete fertilizer.** Apply a complete fertilizer each spring to the garden. Broadcast after plowing at the rate of 2 to 4 pounds to the 100 square feet, or 800 to 1600 pounds to the acre; harrow or rake into the topsoil. In the farm garden, where a heavy application of manure is made annually, superphosphate may be substituted for the mixed fertilizer. The rate and method of application should be the same as of manure without superphosphate. However, even where superphosphated manure is applied, 1 to 2 pounds of mixed fertilizer to the 100 square feet can be applied to advantage in the row just before planting.

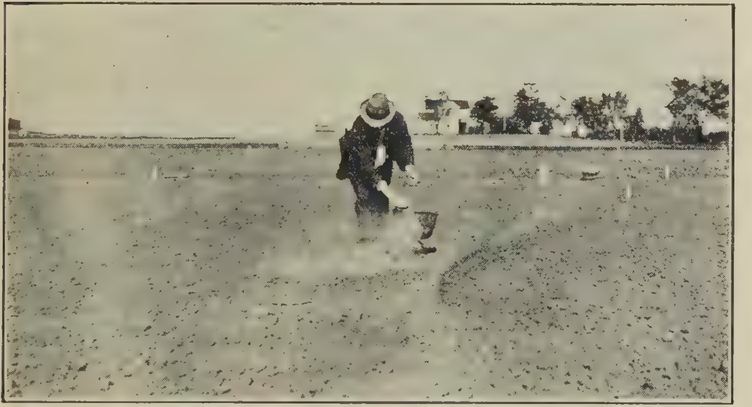

FIG. 212. APPLYING FERTILIZER TO THE GARDEN.

Apply a complete fertilizer each spring to the garden. Broadcast after plowing at the rate of 2 to 4 pounds to the 100 square feet and harrow or rake into the topsoil.

**B. Choose the proper analysis.** For the home garden, it is impracticable to choose a special analysis of fertilizer for the different crops. Instead, apply a high-analysis mixed fertilizer such as the 5–10–5 or the 4–12–4. Where manure is applied regularly, use the 4–12–4; otherwise, the 5–10–5. If a concentrated fertilizer is preferred, use the 10–20–10 and reduce the rate of application by half. If the growth of the crops indicates the need of more nitrogen, apply a side-dressing of nitrate of soda or sulfate of ammonia along either side of the row, at the rate of 1 pound to 75 or 100 feet of row.

In choosing the analysis of fertilizer to use in the commercial production of vegetables, take into consideration the individual crop and the character of the soil. For upland soil, a ratio between nitrogen, phosphoric acid, and potash of 1–2–1 can well be considered a standard. With the application of manure, increase the phosphoric acid content to the ratio of 2–5–2 or even 1–3–1. On muck or peat soils, increase the potash and reduce the nitrogen. Analyses with ratios of 1–2–3, 1–4–6, and 0–1–1 should be considered by the grower with muck land. The following analyses are extensively used on muck soils: 3–12–18, 0–10–10, 4–8–12, 5–20–10, and 4–8–8.

Suggestions for fertilizing treatment of the more common commercially grown vegetables when produced on mineral soils, are given in Table XLVII.

**C. Select a good formula.** Consider the formula in selecting a fertilizer for vegetables. It is desirable that the nitrogen come from several sources, at least part from nitrate of soda and part from sulfate of ammonia. If the soil contains an excess of lime, that is, has a reaction of *p*H 7 or above, use for the fertilization of most vegetables a mixture in which the nitrogen is supplied largely by sulfate of ammonia. An animal or a fish ammoniate, such as animal tankage or dried ground fish scrap, should be contained in sufficient amounts to prevent the fertilizer from lumping. A mixture in which one-third of the nitrogen is supplied as nitrate of soda, one-third as sulfate of ammonia, and one-third as tankage or as fish scrap, makes an excellent fertilizer for the home vegetable garden; but is too expensive for extensive commercial use.

Satisfactory materials are generally used to supply the nitrogen in high-analysis fertilizers which contain 4 to 5 per cent nitrogen. The ordinary commercial mixture on the market with this amount of nitrogen will prove satisfactory for the home vegetable garden or for commercial production. The phosphoric acid normally comes from superphosphate, and the potash from muriate of potash or some of the other standard potash salts.

FIG. 213. LETTUCE GROWN ON MUCK.

In fertilizing vegetables on muck or peat soils, increase the potash and reduce the nitrogen.

In the commercial production of vegetables it is desirable to have definite information as to the make-up of the fertilizer.

## TABLE XLVII *

### Fertilizers for Vegetable Crops Grown on Mineral Soils

| Crop | Sandy Soils | | Loam and Silt Loam Soils | |
|---|---|---|---|---|
| | Approved Analyses | Pounds per Acre | Approved Analyses | Pounds per Acre |
| Asparagus | 8–16–16<br>5–10–10<br>4–8–8 | 925<br>1,500<br>1,850 | 10–20–10<br>5–10–5 | 750<br>1,500 |
| Brussels sprouts, cauliflower, celery, onions, and early cabbage | 10–10–10<br>7–7–7 | 1,000<br>1,450 | 10–20–10<br>5–10–5 | 750<br>1,500 |
| Lettuce | 8–16–16<br>5–10–10<br>4–8–8 | 625<br>1,000<br>1,250 | 10–20–10<br>5–10–5 | 500<br>1,000 |
| Beets, carrots, parsnips, and root crops (12 to 18 inches between rows) † | 8–16–16<br>5–10–10<br>4–8–8 | 925<br>1,500<br>1,850 | 10–20–10<br>5–10–5 | 700<br>1,400 |
| Snap beans (market) | 8–16–16<br>5–10–10<br>4–8–8 | 375<br>600<br>750 | 6–18–6<br>4–12–4 | 400<br>600 |
| Field beans and snap beans for canning | 8–16–16<br>5–10–10<br>4–8–8 | 200<br>300<br>400 | 6–18–6<br>4–12–4 | 200<br>300 |
| Cucumbers, squash, pumpkins | 8–16–16<br>5–10–10<br>4–8–8 | 475<br>750<br>950 | 5–20–5<br>4–16–4 | 500<br>600 |
| Melons | 8–16–16<br>5–10–10<br>4–8–8 | 625<br>1,000<br>1,250 | 10–20–10<br>5–10–5 | 500<br>1,000 |
| Domestic and late cabbage | 8–16–16<br>5–10–10<br>4–8–8 | 475<br>750<br>950 | 10–20–10<br>5–10–5 | 500<br>1,000 |
| Peas (market) † | 8–16–16<br>5–10–10<br>4–8–8 | 375<br>600<br>750 | 5–20–5<br>4–16–4 | 400<br>500 |

TABLE XLVII—*Continued*

| Crop | Sandy Soils | | Loam and Silt Loam Soils | |
|---|---|---|---|---|
| | Approved Analyses | Pounds per Acre | Approved Analyses | Pounds per Acre |
| Peppers and eggplant | 8–16–16 | 625 | | |
| | 5–10–10 | 1,000 | 10–20–10 | 500 |
| | 4–8–8 | 1,250 | 5–10–5 | 1,000 |
| Potato (row application) | 8–16–16 | 925 | | |
| | 5–10–10 | 1,500 | 10–20–10 | 600 |
| | 4–8–8 | 1,850 | 5–10–5 | 1,200 |
| Sweet corn (market) [†] | 8–16–16 | 475 | | |
| | 5–10–10 | 750 | 6–18–6 | 400 |
| | 4–8–8 | 950 | 4–12–4 | 600 |
| Tomatoes (market).......... | 8–16–16 | 625 | | |
| | 5–10–10 | 1,000 | 6–18–6 | 700 |
| | 4–8–8 | 1,250 | 4–12–4 | 1,000 |
| Tomatoes (canning) | 8–16–16 | 625 | | |
| | 5–10–10 | 1,000 | 5–20–5 | 600 |
| | 4–8–8 | 1,250 | 4–16–4 | 750 |
| Spinach, chard, and other crops grown for greens | 10–10–10 | 750 | 10–20–10 | 500 |
| | 7–7–7 | 1,050 | 5–10–5 | 1,000 |

[*] Cornell Extension Bul. 281.

[†] For root crops in 24- to 30-inch rows and for sweet corn and peas for canning, apply at about half the respective rates as stated.

**Manure.** The recommendations given above are for vegetables grown on soil where less than 10 tons of manure is applied, which received manure the year before, or where sod residues or soil-improving crops have been incorporated. When more than 10 tons of manure is used on the land the year the vegetable crop is grown, select a ratio higher in phosphoric acid than that suggested. Use a rate of application which will supply a little less nitrogen and potash. Example: In place of a 1–3–1 ratio for tomatoes on silt soil, use with manure a 1–4–1 ratio such as a 5–20–5 analysis, applying 600 pounds to the acre.

**Band applications.** The recommendations given in the table (except for potatoes) are based on broadcast applications. Experimental evidence indicates that when fertilizer is applied in bands near the row, the rate of application may be reduced. It is dangerous to apply fertilizer directly in the row, especially with peas and beans.

**Side-dressing.** Crops planted on sandy soils are likely to show a profitable response to a side-dressing of 100 to 200 pounds per acre of nitrate of soda, sulfate of ammonia, or a comparable quantity of nitrogen from some other readily available nitrogen carrier Crops on heavier soils should receive a side-dressing of nitrogen whenever growth is slow.

This necessitates either the purchase of a public-formula mixed fertilizer or the practice of home-mixing. Consequently, unless a satisfactory mixed fertilizer can be purchased on the public- or open-formula basis, the commercial producer should consider home-mixing.[9]

**D. Apply properly.** Heavy applications of fertilizer should be applied broadcast; otherwise, injury to seed germination or to the young plant may result. For the home garden, broadcast at least part of the fertilizer after plowing, and mix it with the surface inch or two of soil, by harrowing or raking. In addition to the broadcast application, use 300 to 500 pounds to the acre in the row, care being taken that it does not come in contact with the seed. Also plan to top-dress the growing crop with 75 to 100 pounds to the acre of nitrate of soda or sulfate of ammonia when additional nitrogen is needed for satisfactory growth.[10]

FIG. 214. A POTATO FIELD IN NEW JERSEY.

In the commercial production of vegetables it is desirable to have definite information as to the make-up of the fertilizer.

**E. Apply lime when needed.** The need of lime will depend on the acidity of the garden soil and on the character of the crop. Both these factors must be considered in determining the liming practice to follow. Unless a soil is acid in character, the application of lime may injure rather than benefit most vegetable crops. The crops themselves vary in their tolerance to acidity, that is, they vary in their lime needs. Watermelons require an acid soil. Potato scab is difficult to control in an alkaline soil. Such vegetables as onions, beets, chard, and cauliflower are extremely sensitive to soil acidity.

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[9] See Chapter VII for home-mixing of fertilizers.

[10] See Chapter VII for methods of applying fertilizer.

Consequently, where the soil is found upon testing to be extremely acid, or where the crop to be grown requires soil well supplied with lime, apply lime in amounts to counteract the acidity to the extent of satisfying the needs of the crop to be grown. After the initial application, apply 1 ton of limestone, ½ ton of burned lime, or ¾ ton of hydrated lime every few years as its need is indicated by a soil test. Do not apply lime directly for potatoes, and only sparingly to any other crop in the potato rotation. At all times avoid overliming in vegetable production.[11]

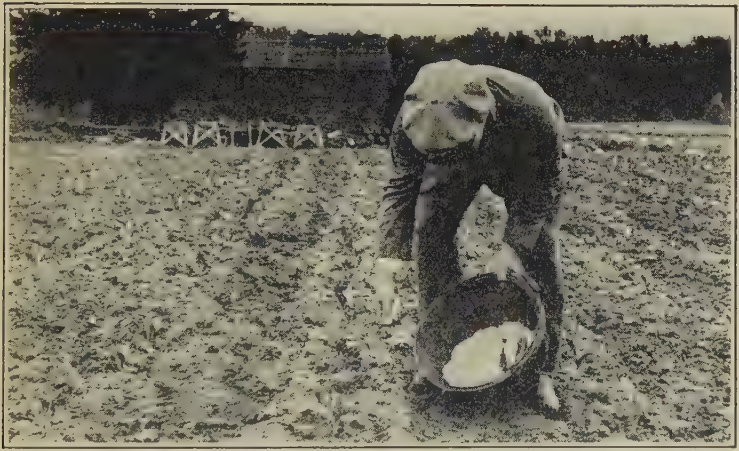

FIG. 215. TOP-DRESS CABBAGE WITH NITRATE OF SODA.

Top-dress the growing crop with 75 to 100 pounds to the acre of nitrate of soda or sulfate of ammonia when needed for satisfactory growth.

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[11] See Chapter VI for determining the need for lime, applying lime, and tolerance of crops to acidity.

## 3. Fertilizing Flowers

In general, flowers require similar soil conditions to most vegetables and respond to similar fertilizer treatment. The same as vegetables, they vary in their tolerance to soil acidity. Some, such as azaleas, daisies, salvia, and many of the rock-garden plants, do best on very acid soils, whereas most others do best when the soil is very slightly acid to neutral. Where desired, the acidity of the soil may be increased by the application of aluminum sulfate (common alum). Table XLVIII gives the amount to apply to produce the desired acidity.

TABLE XLVIII *

Amounts of Aluminum Sulfate to Apply in Acidifying Soils

| Reaction of Soil to be Acidified | Amount to Apply per Square Yard |
|---|---|
| Neutral to strongly alkaline (*p*H 7 to *p*H 8) | $\frac{3}{4}$ pound |
| Slightly acid (*p*H 6 to *p*H 7) | $\frac{1}{2}$ pound |
| Moderately acid (*p*H 5.5 to *p*H 6) | $\frac{1}{4}$ pound |

* Cornell Extension Bul. 281.

Apply the aluminum sulfate to the surface and water thoroughly to dissolve and to wash it into the surface 6 to 8 inches. Delay planting for a week or ten days after treatment is applied.

In the production of flowers maintain a high organic-matter content of the soil. For this purpose use rotted manure, compost, leaf mold, or peat moss. The last two materials increase acidity and for this reason are especially well suited for use where a high degree of soil acidity is desired. If dealing with a heavy-textured soil poorly suited to flowers, for small flower beds consider the possibility of removing the surface 8 or 10 inches and replacing with a mellow loam.

For potted plants the preparation of the soil is of great importance.[12] Select a mellow garden loam or prepared compost preferably having a slightly acid reaction ($p$H 6 to $p$H 7). To 2 parts of this material add 1 part of rotted manure, or decomposed leaf mold. Incorporate with this mixture a 5–10–5 fertilizer at the rate of 1 pint to 4 bushels. For rapidly maturing house plants, no further fertilization will be necessary, but for those living over long periods, such as begonias, ferns, geraniums, and ivies, additional fertilizer should be applied. Use nitrate of soda or sulfate of ammonia and apply in liquid form. Dissolve in water using 1 ounce to 1 gallon of water and apply at the rate of a cupful monthly to each medium-sized pot. Apply only when the soil is moist.

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[12] See General Information at end of chapter on making compost.

Suggestions for fertilizing the more common garden flowers is given in Table XLIX.[13]

## 4. Preparing and Fertilizing Greenhouse Soils

Soils for greenhouse use require special preparation. Almost unlimited expense can be justified in making them ideally suited, both physically and chemically, to the production of the plants. To control diseases of various kinds, frequent soil sterilization, or the occasional changing of the greenhouse soil, is necessary. The efficient management of such soils is an art requiring the use of all available scientific information not only on soils but also on plant nutrition and on disease and insect control as well.

The fertilization of vegetable crops grown under glass should be the same as outlined for field production, except that the rate of application may be considerably increased. Efficient fertilization requires having available constantly all the nutrients the crops can advantageously utilize, and at the same time avoiding injury because of excessive amounts. The fertilizer is often applied in solution for greenhouse plants.[14]

[13] For detailed information on fertilizing florists' crops see Cornell Ext. Bul. 281.

[14] See General Information at end of chapter for information on the preparation of soil material for greenhouse use.

## TABLE XLIX *

### RATE OF APPLICATION OF FERTILIZER MATERIALS FOR GARDEN AND GREENHOUSE FLOWERS

| Materials | Method of Application | Rate of Application |
|---|---|---|
| Dried blood | Solution | 3-inch pot to 3 bushels of soil, or 2 pounds per 100 square feet |
| Horn shavings | Dry | 4-inch pot to a bushel of soil |
| Leaf mold | | Same as for peat |
| Lime | | Apply to correct acidity |
| Manure (cow or horse) | As fertilizer | From 10 to 20 tons per acre, or 4 bushels per 100 square feet of soil |
| | As mulch | 1 inch deep on top of soil |
| Manure (poultry, rabbit, or hog) | | 5 tons per acre, or 1 bushel per 100 square feet of soil |
| Mixed fertilizer 4–12–4; 5–10–5 | Dry | From 2 to 3 pounds per 100 square feet of soil, or 3-inch pot to 3 bushels of soil, or 1 teaspoonful to 5-inch pot of soil |
| Mixed fertilizer 10–20–10; 15–30–15 | Dry | 1 pound or less per 100 square feet of soil, or 2-inch pot to 3 bushels of soil, or ½ teaspoonful to 5-inch pot of soil |
| | Solution | 1 ounce to 2 gallons of water |
| Muriate of potash | Dry | 500 pounds per acre, or 1 pound per 100 square feet of soil |
| | Solution | 1 pound in 10 gallons of water applied to 100 square feet of soil, or ½ cup of solution to 5-inch pot of soil |
| Nitrate of soda | | Same as sulfate of ammonia |
| Peat | Incorporated in topsoil | 2 bushels to 100 square feet of soil for garden |
| | Mulch | ½-inch layer |
| Sulfate of ammonia | Dry | 1 pound to 100 square feet of soil |
| | Solution | 1 pound in 10 gallons of water applied to 100 square feet of soil, or 1 cupful of solution to 5-inch pot of soil |
| Sulfate of potash | | Same as for muriate of potash |
| Superphosphate (16 or 20 per cent | Dry | 1000 pounds per acre, 5 pounds per 100 square feet on benched soil, 4-inch pot to bushel of soil |
| Tankage | Dry | 4-inch pot to 3 bushels of soil; 5 pounds per 100 square feet |
| Urea | Solution only | 1 ounce to 7 gallons of water applied to 100 square feet of soil, or 1 cupful of solution to 5-inch pot of soil |

* Cornell Extension Bul. 281.

The fertilizer recommendations for flowers in Table XLIX are given on the basis of greenhouse as well as garden production.

## 5. Fertilizing the Lawn

There are two distinct types of lawns: one composed largely of Kentucky bluegrass and white clover; and the other of acid-tolerant grasses such as bent grass, redtop, and fescue. The former type is suited to soils well supplied with lime but grows satisfactorily on moderately acid soils. When properly fertilized, such a lawn will do well with the minimum attention. However, the latter type is sometimes preferred as the turf is thicker, of a finer texture, and causes less staining of clothing. It requires more frequent cutting, fertilizing, and watering than the bluegrass-white clover type.

Fig 216. Bent-Grass Turf, Six Weeks Old, Started from Stolons. (U. S. Dept. of Agr. and U. S. Golf Assoc.)

A bent-grass lawn is sometimes preferred to a bluegrass lawn as the turf is thicker, of a finer texture, and causes less staining of clothing.

Since the bent grass can be developed on a very acid soil, certain weeds may more easily be controlled than in lawns suited only to slightly acid soils. However, weeds are tolerant to both acidity and alkalinity, and their control in the lawn is more a matter of fertility level and of management, than it is of soil acidity. The fertilization of the lawn depends on the type of turf, and especially on the amount of white clover present.

**Procedure:**

A. Apply lime only when needed.
B. Consider using manure or other organic material.
C. Fertilize liberally.
D. Give the soil proper treatment prior to seeding a lawn.
E. Seed the proper grass mixture.

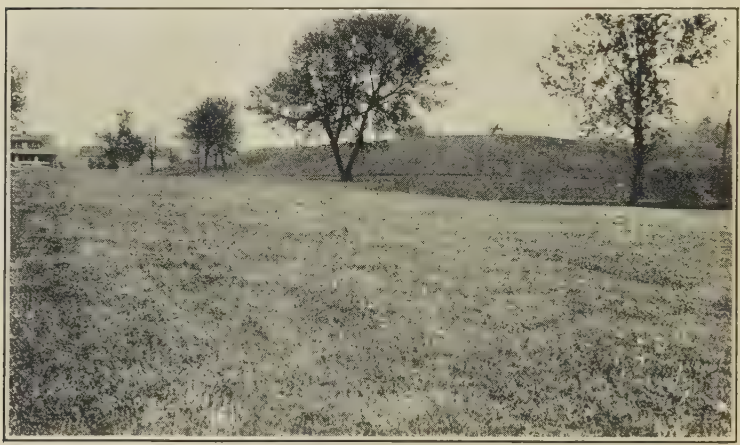

FIG. 217. BLUEGRASS AND WHITE-CLOVER LAWN.

Where the sward consists largely of Kentucky bluegrass and white clover and the soil is acid, lime may be needed.

**A. Apply lime only when needed.** In determining whether or not to lime a lawn, consider first the soil reaction, and second, the type of vegetation of which the sward is composed. Where the sward consists largely of Kentucky bluegrass and white clover and the soil is acid, lime may be needed. Test the soil, and if the acidity is in excess of *p*H 6, lime should be applied. The rate of application should never be heavier than the amount necessary to neutralize the surface soil.

Many lawns have been injured by overliming. The appearance of moss in a lawn is as often due to alkalinity as to acidity of the soil. The same is true of weeds. In a lawn, moss and weeds are the result of either excess acidity or alkalinity or of a low fertility level. Excess shade is another contributing factor to the development of moss.

As a general rule do not apply lime to bent grass and fescue swards or to the grass swards of the South, which commonly consist of such acid-tolerant grasses as Bermuda, carpet and St. Augustine grass. Lawns in the western states seldom require liming. Before liming Kentucky bluegrass and white-clover swards, make certain that the surface soil is acid. In applying lime to an established lawn do not attempt to satisfy the lime requirement of the surface soil with a single application. Instead make several light applications at intervals of two or three years. This gives the lime an opportunity of working down into the soil and prevents the accumulation of an excess in the surface inch. If the surface soil is less acid than *p*H 6, or if the acidity has been reduced to this point by liming, additional lime should not be needed even for Kentucky bluegrass and white-clover lawns so long as liberal applications of superphosphate or of non-acid-producing mixed fertilizer are used, and any nitrogenous top-dressings made consist of nitrate of soda instead of sulfate of ammonia.

In liming an established lawn do not apply at one time more than 4 pounds of ground limestone, 3 pounds of hydrated lime, or 2 pounds of burned lime to 100 square feet. Apply the lime broadcast during the late fall, winter, or very early spring while the grass is dormant.

**B. Consider using manure or other organic material.** Frequently it is desirable to apply an organic material to established lawns. Such treatment is particularly beneficial where, because of either climatic or soil conditions, the lawn is subject to drought injury. A mulch of organic matter has been found very helpful in conserving moisture of heavy clay soil. It is also beneficial in keeping the soil cool. If there is a large proportion of white clover in the sward, the mulch is of less importance on account of the shade produced by the clover leaves.

A number of organic materials may be applied to lawns. Of these ordinary farm manure is frequently used. When well rotted and free from weed seed it is a satisfactory material, though often objectionable because of its disagreeable odor. Artificial manure when adequately decomposed is an excellent organic material for use on lawns. Pulverized poultry manure, dried sheep manure, cottonseed meal, castor pomace, and peat are other materials to consider. If mowed frequently, the clippings may be left on the lawn as a source of organic matter.

Organic materials should be applied when the sward is dormant, preferably in the early spring. The rate of application will depend on the concentration of the material used. Apply at the following approximate rates to 100 square feet: rotted farm manure, artificial manure, and peat, 25 to 50 pounds; cottonseed meal and castor pomace 2 to 3 pounds.

**C. Fertilize liberally.** The lawn should be fertilized liberally. Start each season by top-dressing with a mixed fertilizer in the early spring before the grass starts growth; choose an analysis high in nitrogen such as the 8–6–4 or 10–6–4 for grass swards, but where white clover constitutes a good proportion of the sward use a mixture with less nitrogen such as the 5–10–5. Apply at the rate of 1 to 2 pounds to 100 square feet. If spring growth has started, apply the fertilizer when the grass is dry, and unless washed down by a soaking rain, water thoroughly to get the fertilizer into the soil and prevent burning the young grass.

Where the lawn consists of the acid-tolerant grasses, supply the nitrogen as sulfate of ammonia. Use the following formula:

10 pounds sulfate of ammonia
8 pounds 16 per cent superphosphate
1½ pounds muriate of potash

For bluegrass lawns substitute nitrate of soda for the sulfate of ammonia, and if white clover occurs with the bluegrass, reduce the amount of nitrate of soda from 10 to 5 pounds. In either case, the amount of fertilizer will be sufficient for 1000 square feet of lawn. Apply immediately after mixing, since these mixtures are subject to lumping on standing. Rake over any thin spots in the turf, and reseed prior to or at the time the fertilizer is applied.

In order to maintain a vigorous growth throughout the season, apply a top-dressing of sulfate of ammonia or of nitrate of soda a month or six weeks after the complete-fertilizer treatment is made. Five or 6 pounds to 1000 square feet will suffice. Use nitrate of soda for bluegrass and white-clover lawns, and sulfate of ammonia for bent grass, redtop, and other grass swards. Apply when the grass is dry just before a rain, or plan to water the lawn thoroughly immediately after the treatment. Repeat the application at four- to six-week intervals during the growing season when the condition of the turf indicates the need of additional nitrogen.

**D. Give the soil proper treatment prior to seeding a lawn.** In establishing a new lawn, first make certain that the soil is adequately drained. Unless it is naturally well drained, install a tile-drainage system.[15] See to it that the surface material to a depth of 6 to 8 inches consists of topsoil, well supplied with organic matter and preferably of a heavy-loam texture. If the acid-tolerant grasses are to be seeded, make certain that the surface soil material is acid in character. Unless it is sufficiently acid, apply aluminum sulfate in amounts necessary to produce the desired soil reaction.[16] If, on the other hand, the sward is to consist of Kentucky bluegrass and white clover, apply approximately enough lime to neutralize the acidity of the surface soil.[17] Also incorporate organic material by adding 1 pound of well-rotted manure, artificial manure, or peat moss to the square foot of surface, unless the soil is naturally well supplied with organic matter. Work this organic material into the surface to a depth of 2 to 4 inches. Apply 15 to 20 pounds of a complete fertilizer to 1000 square feet of surface in the late summer or early fall just prior to seeding. Rake or harrow thoroughly to mix the fertilizer with the surface inch or two of soil. In selecting the fertilizer, choose one or the other of the formulas given on page 472, depending on the type of lawn that is to be established.

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[15] See Chapter III, Soil Drainage.

[16] For acidifying soils, see page 466.

[17] See Chapter VI for testing soil for acidity.

**E. Seed the proper grass mixture.** Plan to seed the lawn in the late summer or early fall. In the northern states, seed the last week in August and proportionately later in the warmer climate of the South. Seeding may be done in the early spring, but generally better results are secured from fall seedings. Seed at the rate of 1½ to 3 pounds to 1000 square feet. Go over the ground twice, seeding in opposite directions in order to secure a uniform distribution of the seed. Avoid seeding when a strong wind is blowing. Rake or harrow lightly so as to cover the seed. Southern grasses such as Bermuda and carpet grass are most successfully established with stolons instead of by seeding. Bent grass also is often propagated with stolons.

For bluegrass lawns, seed a mixture of 4 parts by weight of Kentucky bluegrass and 1 part of annual rye grass. In heavily shaded areas, substitute rough-stalked bluegrass for the Kentucky bluegrass. Where a white-clover and bluegrass mixture is desired, replace the rye grass with white clover in the proportion of 1 part by weight of genuine wild white clover[18] to 10 parts of bluegrass. On acid soils, seed bent grass either alone or mixed in equal amounts with Chewing's fescue. The Rhode Island variety of bent grass is the best for the ordinary lawn. The creeping bent produces a finer turf and should be used for golf greens or other places where the finest-quality turf is desired. Unfortunately, creeping bent grass requires frequent clipping and watering to keep it in the best condition. Another possible objection to the creeping bent is the high cost of seed. Seed bent grass at the same rate as bluegrass. On a small area, or if expense is of minor importance and it is desired to secure a good sward quickly, use bent-grass stolons instead of seed. If fescue sward is preferred to bent grass, seed red fescue, preferably Chewing's New Zealand variety, at the rate of 8 to 10 pounds to 1000 square feet.

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[18] Wild white clover seed is produced in England. It has recently appeared on the American market, and is superior to the common white Dutch clover for lawn seedings.

The following is a good general-purpose mixture for the northern states. Sow it at the rate of 2 to 3 pounds to the 1000 square feet:

| | |
|---|---|
| Kentucky bluegrass | 50 per cent |
| Rhode Island bent grass | 15 per cent |
| Rough-stalked bluegrass | 10 per cent |
| Redtop | 10 per cent |
| Chewing's fescue | 10 per cent |
| Wild white clover | 5 per cent |

## GENERAL INFORMATION

### 1. How to Make Compost

Commercial growers very often prepare compost for their greenhouse benches by fertilizing and manuring a field soil liberally and growing several green manure crops in succession. Directions for this field method of preparing compost are given in detail in Bulletin 281 of the Cornell Experiment Station. If relatively small amounts of compost are needed or if land is not available for field preparation, the compost-pile method may be used. This consists of building a pile with alternate layers of soil and manure, and of incorporating additional plant nutrients by the addition of fertilizer materials. Lime may be incorporated in addition to fertilizer if the soil is sufficiently acid to require it.

The following specific directions for making compost by the pile-method are from Cornell Extension Bulletin 281.

1. Select a desirable type of soil, preferably a sandy loam sod.
2. Pile alternate layers of soil and manure, 8 inches of soil and 3 inches of manure.
3. Spread superphosphate on top of each layer of manure, using 10 pounds to 100 square feet of soil.
4. Spread muriate or sulfate of potash on each layer of manure at the rate of 2 pounds to 100 square feet.
5. Lime should not be used unless the soil test shows the need for it (page 275). The soil should be slightly acid.
6. Hollow the top of the pile to catch water.
7. Keep the soil moist.
8. Turn the compost every three months.

This will be ready to use in from nine months to one year.

## COMMUNITY STUDIES

1. Visit several vegetable gardens in the community and determine the character of the soil and its fitness for gardening purposes.
2. If an unproductive garden soil can be located, examine it and determine, as far as possible, the cause of its unproductivity.
3. Determine the lime, manure, and fertilizer practice followed in the treatment of several local kitchen gardens. To what extent are green-manure crops grown?
4. Study the tillage practices.
5. Determine whether or not cover crops are grown.
6. If vegetables are grown commercially in the community, study the soil-management practices followed by at least one good commercial grower.
7. Outline a soil-management system for your home garden or some other one that is typical of those in the community.
8. Visit a commercial greenhouse, and determine the fertilizer practices followed for vegetables or flowers grown under glass.
9. How is the soil prepared before it is put into the benches?
10. Outline a procedure for the successful fertilization of house plants.
11. Study the character of vegetation and record the kinds of plants found in several lawns.
12. Secure information as to the treatment followed in connection with at least one good lawn in the community.
13. Outline the procedure to follow in the establishment of a lawn in your local community.

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# CHAPTER XII

## MANAGING FRUIT SOILS

A favorable climate and a suitable soil are the primary requisites for the successful growing of fruit. For commercial production, choose the location with care, making certain that the climate is favorable for the type of fruit to be grown, and that the soil is naturally well drained but not subject to drought. Consider only farms situated in a recognized fruit section, and, even in such a section, secure the services of a fruit specialist if there is any question as to the suitability of the soil.

Two cultural methods are extensively followed in the management of orchard soils: (1) tillage with cover crops, and (2) the sod mulch. Each method has its staunch supporters, and with proper supplementary treatment either will give satisfactory results. If the topography is rough or the surface soil stony, the sod method should be employed with apples and pears. The stone fruits, particularly peaches, require tillage, as do grapes and the bush fruits. Virtually two systems of orchard-soil management have been developed, one for tilled and the other for sod orchards.

A vigorous growth made early in the season is recognized as essential in fruit production. With the young orchard, a rapid and vigorous growth of tree is desired to hasten the date at which profitable crops may be produced, and with the mature orchard it is conducive to the set of fruit and the production of healthy fruit spurs early in the season. The latter is an essential for a good crop of fruit the following year.

This desired growth in the spring and early summer is primarily dependent on an adequate supply of available nitrogen, which can be furnished either by tillage and the return of green-manure crops, or by applying nitrogenous fertilizers.

FIG. 218. A TYPICAL FRUIT SECTION. (Hort. Dept., Ill. Agr. Exp. Sta.)

In choosing a location for commercial fruit production consider only farms situated in a recognized fruit section.

**Operations:**

1. Tilling the orchard.
2. Growing cover crops in the orchard.
3. Fertilizing tilled orchards.
4. Fertilizing sod orchards.
5. Fertilizing small fruits.

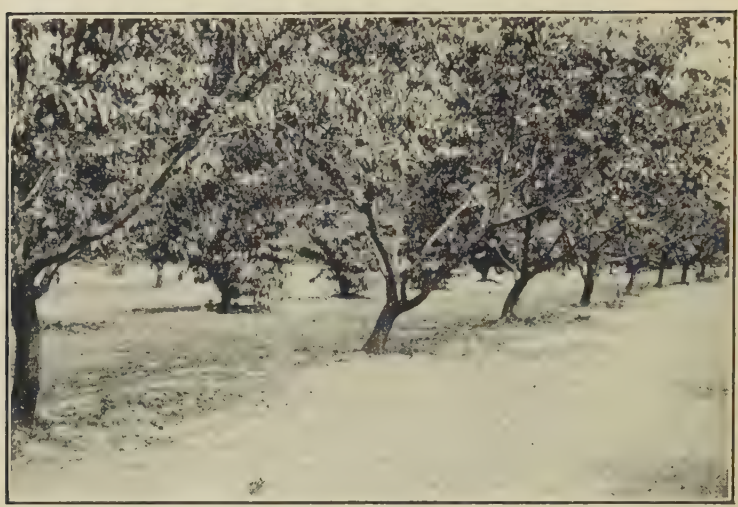

FIG. 219. A WELL-TILLED PEACH ORCHARD. (Agro. Dept., N. Y. State Col. of Agr.)

The stone fruits, particularly peaches, require tillage.

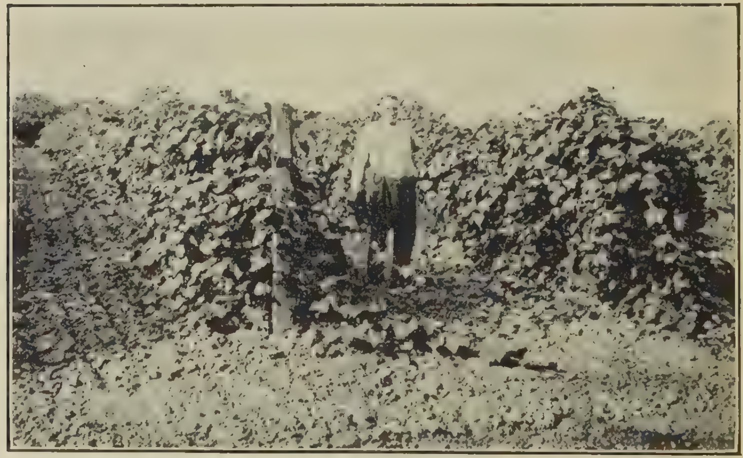

FIG. 220. A WELL-TILLED VINEYARD. (Agro. Dept., N. Y. State Col. of Agr.)

Grapes and the bush fruits must be tilled.

## 1. Tilling the Orchard

Where orchards are tilled, it is essential that this be done at the proper time and that tillage operations cease relatively early in the season. The practice includes plowing or deep disking, followed later in the season with several harrowings.[1]

**Procedure:**

A. Plow or disk.
B. Harrow.

Fig. 221. Disking the Orchard. (Dept. of Pomology, N. Y. State Col. of Agr.)

Plow or disk the orchard either in the late fall or very early spring.

**A. Plow or disk.** Plow or disk the orchard either in the late fall or in the very early spring. Tillage hastens the decomposition of the soil organic matter and the liberation of available nitrogen. By tilling the orchard prior to the blooming period, nitrates will be formed in the soil at a sufficiently rapid rate for a good set of fruit, provided the soil contains an average amount of decomposable organic matter. Except where the soil is subject to erosion or where the trees are susceptible to winter root injury, plow in the late fall. Otherwise, plow just as early in the spring as the soil is in fit condition to be worked. This will generally be April or early May in the North, and March or early April in the South.

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[1] See Chapter IV, Tilling the Soil.

Avoid deep plowing. Five to 6 inches is sufficiently deep for the bearing orchard. Where intercropped, the young orchard may be plowed to a depth of 7 inches if the crop grown between the trees requires a deep seed-bed. As the trees come into bearing, it is well to leave the lower surface soil undisturbed by tillage so that the roots may work up into it. A 5- to 6-inch seed-bed will be found deep enough for the cover crops. On the lighter soils, a large type of cutaway disk, well weighted down, may be used instead of the plow. It is especially suitable where the tractor is used for power.

Fig. 222. A Well-Tilled Orchard.

By frequent cultivation of the orchard keep down the growth of weeds, conserve moisture, and maintain favorable conditions for nitrification.

**B. Harrow.** Work the plowed soil of the orchard every two or three weeks during the spring with a disk or spring-tooth harrow. In this way, keep down weed growth, conserve moisture, and maintain favorable conditions for nitrate formation. Normally, three or four harrowings should be given prior to July.

Tillage should cease about July first. With pears it should cease even earlier when necessary to control blight. Peaches may well be tilled for a month later, but tillage should cease sufficiently early for the successful production of a cover crop.

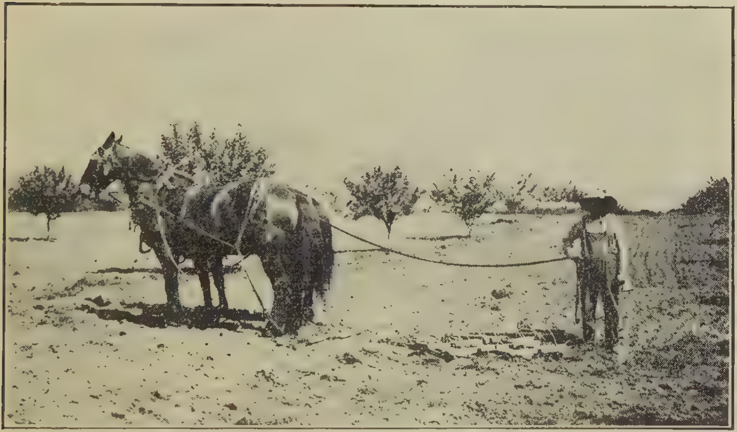

FIG. 223. HARROWING ORCHARDS.

Harrow the orchard to keep down weed growth, conserve moisture, and maintain favorable conditions for nitrate formation.

Late tillage is conducive to continued wood growth, which may not become sufficiently hardened to resist winter injury. As with the date of plowing, that at which tillage should cease depends on location, kind of fruit, and character of soil. In general, it should be earlier and not later than the common practice.

### 2. GROWING COVER CROPS IN THE ORCHARD

Since tillage hastens the destruction of soil organic matter it furnishes increased amounts of nitrates for the trees. Where the surface soil is rich in organic matter, tillage alone will suffice in meeting the nitrogen needs for a period of years. As the organic-matter supply decreases even with rich soils, provision must be made to replenish it. Most fruit soils are relatively low in organic matter, so that from the very beginning cover crops should be grown and returned as green manure to replenish the supply of the tilled orchard.[2]

**Procedure:**

A. Determine the crop to be grown.
B. Seed at the proper time and rate.
C. Plow under as green manure.

**A. Determine the crop to be grown.** Most of the crops used in green manuring are adapted to the orchard. The legumes are naturally to be preferred to the non-legumes, since the soil on which they have been grown is well supplied with nitrates the following spring. This is ideal for fruit. The superiority of legumes over non-legumes as cover crops for the orchard is not fully appreciated.

On soils well supplied with lime, either the annual or biennial variety of sweet clover may be used. Under these conditions, alfalfa is also a good cover crop. Red, alsike, or Ladino clover, may be used where the subsoil is not suited to alfalfa or sweet clover, or where the surface soil contains an insufficient amount of lime for these crops. In the South, crimson clover can be used as a winter cover crop and cowpeas for a summer crop to be plowed under in the fall. On acid soils, in both the North and the South, winter vetch seeded with rye is excellent where the seeding is made relatively late and the orchard not plowed until spring. Other cover crops adapted to orchards are buckwheat, soybeans, oats, rye, rape, and cowhorn turnips. A heavy growth of buckwheat, turnips, or rape may be bothersome at picking time. Weeds are sometimes permitted to grow as a green-manure crop, but the practice cannot be encouraged.

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[2] See Chapter VIII, Leguming and Green Manuring.

**B. Seed at the proper time and rate.**—Seed the cover crops at the time of the last cultivation. This should be relatively early in the summer. The cover crops draw on both the moisture and nitrate supply of the soil, reducing the amount available for the trees. This tends to check new wood growth, to lessen blight injury, and to produce conditions favorable to proper ripening and better coloring of the fruit.

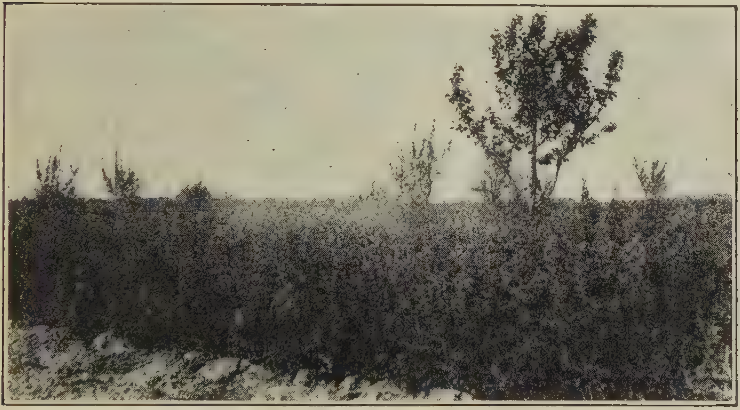

Fig. 224. Sweet-Clover Cover Crop in a Young Orchard. (Dept. of Pomology, N. Y. State Col. of Agr.)

On soils well supplied with lime, either the annual or biennial variety of sweet clover may be used.

The actual date at which the cover crop should be planted will vary with climate, soil, age of tree, kind, and even variety of fruit. In the North, seed in early July in bearing orchards, and somewhat later in young orchards. In the South, seed a few weeks later than in the North. The seeding should be earlier for pears than for apples, as a means of blight control, and fully a month later for the bearing peach orchard, which needs a good supply of nitrates for the full development of the fruit. Seed the cover crop somewhat earlier in soils that are well supplied with organic matter than in those deficient in this constituent. The prevailing practice is to seed too late rather than too early, especially in apple and pear orchards.

**C. Plow under as green manure.** Plow the cover crop under when still green. Where a summer crop, such as buckwheat, cowpeas, or rape is grown, plow the orchard in the fall. Where fall plowing is not feasible, choose a cover crop that remains green over winter. Plowed under while green, the organic matter decomposes quickly, thus furnishing nitrates promptly. If the cover crop is permitted to mature, decomposition is slow and not only is nitrate formation retarded but also the soil supply of nitrate may be temporarily reduced.

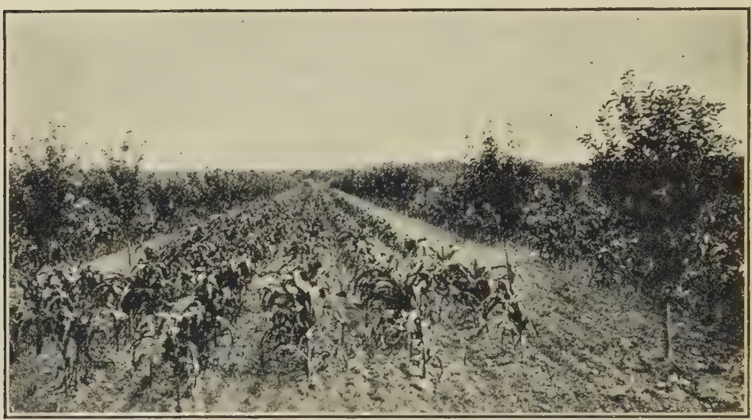

FIG. 225. SWEET CORN GROWING IN A YOUNG ORCHARD. (Dept. of Hort., Ill. Agr. Exp. Sta.)

Where cash crops are grown in the young orchard, fertilize them in the same way as when grown under field conditions.

### 3. FERTILIZING TILLED ORCHARDS

Tillage, combined with the production of cover crops and their return as green manure, has been found to satisfy largely, if not entirely, the plant-food needs of fruit trees. In the tilled orchard, base the fertilizer treatment largely on the needs of the cover crops or the cash crops grown.

**Procedure:**

A. Fertilize cover crops rather than trees.
B. Manure or fertilize trees when necessary.

**A. Fertilize cover crops rather than trees.** Apply fertilizer for the cover crops grown in the tilled orchard. Superphosphate at the rate of 200 to 400 pounds to the acre every other year will generally suffice for legumes. On sandy soil, and others responding to potash, apply 50 to 100 pounds of muriate of potash in addition to the superphosphate. On poor soils, besides the minerals, apply 75 to 100 pounds of nitrate of soda, sulfate of ammonia, or cyanamid to the acre. Though more expensive, equally good results will be secured from an application of 300 to 500 pounds of a mixed fertilizer such as the 5–10–5.

Where cash crops are grown in the young orchard, fertilize them in the same way as when grown under field conditions. The treatment supplies any additional plant-food needs of the young trees that are not entirely satisfied by the soil itself. Where cash crops are grown for several years in a young orchard and liberally fertilized, there should be sufficient residual effect to supply the needs of cover crops for several years.

Lime is of little direct benefit to fruit trees. It may actually injure citrus fruits. Apply it to orchard soils only when cover crops need it for best results. Orchard soils are frequently acid in character, and lime is a requisite for most legumes. The application of lime to very acid soils might increase nitrate formation by hastening the decomposition of organic matter and by increasing the activity of the independent nitrogen-gathering bacteria of the soil. Because of these indirect effects, lime often benefits fruit.

**B. Manure and fertilize trees when necessary.** Where soils are very deficient in organic matter, or where, because of excessive shade, cover crops make an unsatisfactory growth, the trees may require treatment. This can generally be detected by the character and color of the foliage. So long as the tree produces a heavy foliage of dark-green color, it is not in need of nitrogenous fertilizer. Either the failure to set fruit or an unusually heavy "drop" of fruit indicates an insufficient supply of nitrogen. A deficiency of either phosphorus or potassium would normally affect the cover crops

### TABLE L *

Approximate Amounts, in Pounds to a Tree, of Readily Available Nitrogenous-Fertilizer Materials (Nitrate of Soda, Sulfate of Ammonia, Calcium Nitrate, or Cyanamid)

| Age of Trees | In Sod | | Cultivated | |
|---|---|---|---|---|
| | Good Vigor | Low in Vigor | Average Vigor ‡ | Low in Vigor |
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| | | Apples | | |
| Years | | | | |
| 1 to 2† | ⅛ to ¼ | ¼ to 1 | 0 to ¼ | ¼ to ½ |
| 3 to 5 | 1 to 2 | 1½ to 3 | ¼ to ½ | ½ to 2 |
| 5 to 10 | 2 to 3 | 3 to 4 | ½ to 2 | 2 to 3 |
| 10 to 15 | 3 to 5 | 4 to 6 | 2 to 3 | 3 to 4 |
| 15 to 20 | 5 to 7 | 6 to 8 | 3 to 4 | 4 to 6 |
| 20 to 25 | 7 to 9 | 8 to 12 | 4 to 6 | 6 to 9 |
| 25 to 30 | 9 to 12 | 12 to 16 | 6 to 8 | 9 to 10 |
| Over 30 | 12 to 15 | 16 to 20 | 8 to 10 | 10 to 12 |
| | | Pears | | |
| 1 to 3 | 0 to ½ | ¼ to 1 | 0 to ¼ | ¼ to 1 |
| 3 to 6 | ½ to 1½ | 1½ to 2 | ¼ to 1½ | 1 to 2 |
| 6 to 10 | 1½ to 3 | 3 to 5 | 1½ to 2½ | 2 to 3 |
| Over 10 | 3 to 4 | 5 to 7 | 2½ to 4 | 3 to 5 |
| | | Peaches, cherries, and plums | | |
| 1 to 3 | On light soils | | 0 to ½ | ½ to 1 |
| 3 to 5 | On light soils | | ½ to 2 | 1 to 3 |
| Over 5 | On light soils | | 2 to 4 | 3 to 5 |

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* Cornell Extension Bul. 281.

† The sod should not be allowed to form closer than 1 to 2 feet from the trunk in newly planted trees. A good moisture supply is more important than fertilizer at that age. Fertilizer should never be applied within a circle 1 foot from the trunk.

‡ Cultivated orchards in soils rich in organic matter may show little or no response to fertilizer and should be used only after trial under the particular condition.

before it would the trees. Peaches and cherries, even when tilled, should be fertilized. This is also true of grapes and of the citrus fruits such as oranges and lemons.

Where nitrogen is needed, apply in the form of nitrate of soda, sulfate of ammonia, or cyanamid at the rate of 2 to 4 pounds to the tree for peaches and cherries, and 5 to 10 pounds for full-grown apple and pear trees.[3] For grapes broadcast 75 to 100 pounds to the acre. Always apply the nitrogenous fertilizer early in the spring prior to the blooming period. Plow into the soil, or, if applied after plowing, harrow in. Never apply fertilizer closer than one foot from the tree trunks. If available, farm manure instead of the nitrogenous fertilizer may be applied at the rate of 8 to 10 tons to the acre. Watch the trees carefully and do not use fertilizer nitrogen so long as, by tillage and the return of green-manure crops, an adequate supply of nitrates is furnished.

Citrus fruits, in common with the other tree fruits, are benefited chiefly by nitrogen. They differ, however, in that they give best results when part of the nitrogen is supplied as organic ammoniates in the fall of the year. For citrus fruits, apply 8 to 10 pounds of animal tankage or other organic ammoniate to the tree in the fall, and in the early spring an equal amount of nitrate of soda or sulfate of ammonia.

## 4. Fertilizing Sod Orchards

Where orchards are left in sod, the grass should be cut once or twice each summer. It can be made into hay or left in the orchard as a mulch. Often it is raked up and scattered under the trees. This is the true sod-mulch method of culture. While it conserves soil moisture, it undoubtedly retards nitrate formation, and it harbors mice, which often injure the trees. Where it is practical to utilize the grass as hay, remove it from the orchard. Irrespective of the way in which the grass crop is disposed of, sod orchards must either be fertilized or manured liberally. Where possible, till the young orchard until it comes into bearing. If this cannot be done, it, like the bearing sod orchard, must be well fertilized or manured.

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[3] See Table L for the rate of application of nitrogenous fertilizer for fruit trees.

**Procedure:**

A. Use nitrogenous fertilizer.
B. Apply manure if available.
C. Lime and fertilize the sod.

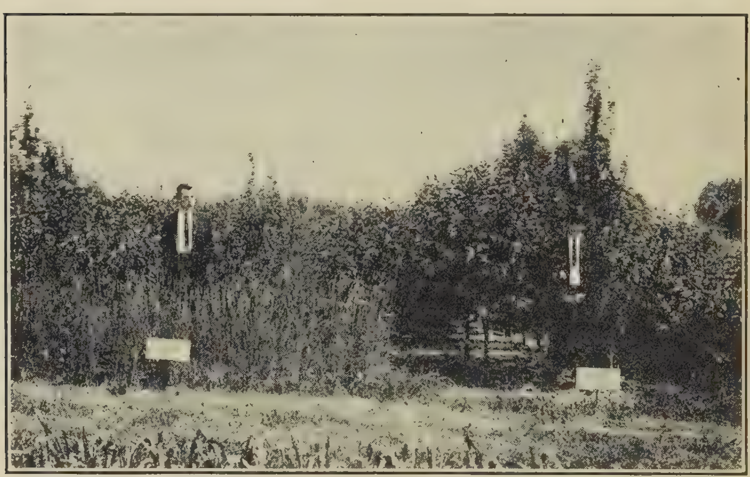

FIG. 226. YOUNG FRUIT TREES; TILLED ON RIGHT, TIMOTHY SOD ON LEFT.

Where possible, till the young orchard until it comes into bearing.

**A. Use nitrogenous fertilizer.** The sod orchard must be furnished with additional nitrogen. The grass competes with the trees for the soil supply, which is insufficient for both crops, especially in the early spring. Also, owing to a depressing effect which grass has on nitrate formation, the supply of available nitrogen is reduced in the sod orchard. Unless the soil supply is augmented, the foliage will become yellowish-green in color, growth will be retarded, and bud formation reduced; also, the set of fruit will be lessened, and the "drop" increased. Essential, then, to successful production with the sod method, is the application of nitrogen in the form of either fertilizer or farm manure.

Nitrate of soda is a good nitrogenous material to use, since the nitrogen is in the nitrate form ready for immediate use by the trees. Sulfate of ammonia is also a good nitrogenous material for the sod orchard. Though less readily available, it is a cheaper form of nitrogen than nitrate of soda. At least part of the nitrogen should be furnished by sulfate of ammonia or cyanamid where the price is materially lower.

The rate of application depends on the size of tree, varying in the bearing orchard from 5 pounds to 15 pounds of nitrate of soda to the tree. Young trees should receive about ¼ pound for each year of their age until they reach the bearing stage. Where sulfate of ammonia or cyanamid is used wholly or in part, reduce the rate of application so as to supply the equivalent amount of nitrogen. In case the sod contains a good proportion of clover or alfalfa use only one-third to one-half the standard amount per tree.

Apply the nitrogenous fertilizer early. This is very essential. The application should be made when the buds begin to swell, which, with apples, is normally about two weeks before blooming. Where sulfate of ammonia or cyanamid is used, the application may be made even earlier. The object is to have the material carried down by rain water to the root zone of the trees ready for use during the blooming period.

Make a broadcast application to each tree. Starting a foot or two from the trunk, scatter uniformly over the surface well past the spread of the branches. If applied when vegetation is dry, temporary burning of the grass, as well as any tree foliage which may be started, will be avoided.

**B. Apply manure if available.** If manure is produced in sufficient quantity on the farm, or if it can be purchased at a reasonable price, it may be used in place of fertilizer in the sod orchard. Since the nitrogen in manure is more slowly available than that in nitrate of soda or even sulfate of ammonia, apply the manure in the late fall or during the winter. Scatter it under the trees, covering the same area as specified for fertilizer, at a rate of about 40 times that specified for nitrogenous-fertilizer materials in Table L.

Avoid the application of excessive amounts of manure, as the residual effect of the nitrogen may hold over long enough to retard the ripening of the fruit. Late applications of a nitrogenous fertilizer material might also have this effect. There is especial danger of retarded ripening when legumes are dominant in the sod. As the result of delayed ripening, the coloring of fruit will be retarded and may not be fully developed by harvest. This adverse effect of nitrogen is the only influence which fertilizer is known to have on coloring.

**C. Lime and fertilize the sod.** Where the orchard is left in sod, make provisions for maintaining a good sod. If the soil is very acid, apply lime, as in the production of field crops. In addition, broadcast 300 to 400 pounds of superphosphate or an 0–20–20 fertilizer to the acre every two years. This combination of lime, phosphorus, and potash often brings in white or alsike clover. If the supply of farm manure is adequate, apply it broadcast to the whole orchard instead of to a restricted area around each tree. An application, made in this way, of 8 to 10 tons of manure annually will not only benefit the fruit but in addition will increase the growth of grass and clover, resulting in a larger hay crop or additional material to be left as a sod mulch. Such a broadcast application of manure, along with superphosphate and enough lime to counteract excess acidity, invariably makes an ideal treatment for the sod orchard.

## 5. Fertilizing Small Fruits

Besides the tree fruits and grapes, various small fruits, such as currants, gooseberries, raspberries, blackberries, and strawberries, require proper fertilization for good yields.

They are ordinarily given clean tillage, though cover crops are sometimes grown. Like the tree fruits, they respond well to nitrogenous fertilizer.

**Procedure:**

A. Fertilize liberally.
B. Apply lime only where soils are very acid.

**A. Fertilize liberally.** The small fruits have much in common with vegetables. They are grown in intensive rather than extensive systems of cropping. They offer large net returns per acre, and are produced on relatively high-priced land. As a result of these conditions, the soil on which they are grown should be liberally fertilized.

In addition to the annual crop of fruit, the plants must make a vigorous new vegetative growth for the production of the next season's crop. The bearing canes of blackberries and raspberries die each fall; strawberries are borne, largely at least, on the new plants produced by runners the previous season. Consequently, as with the tree fruits, the treatment must take into consideration new vegetative growth as well as the immediate yield of fruit.

For best results with strawberries, give the soil a liberal treatment when the bed is prepared. If possible, plow under a good clover sod and apply 500 to 600 pounds of superphosphate and 100 pounds of muriate of potash, or 500 to 600 pounds of an 0–20–10 fertilizer, to the acre. Otherwise plow under 20 tons of superphosphated manure to the acre. If the plants show lack of vigor apply nitrate of soda or sulfate of ammonia as a side-dressing at the rate of 150 to 200 pounds to the acre. Make the application in late summer or early fall rather than in the spring. Excess nitrogen may result in soft berries subject to rot in wet seasons. If neither manure nor legume sod is turned under, a complete fertilizer such as a 5–10–5 should be incorporated with the surface soil when the bed is prepared. Use 800 to 1000 pounds to the acre.

Apply sufficient fertilizer for raspberries and blackberries to produce a good, healthy growth of new canes. On soils low in organic matter, apply 200 to 300 pounds to the acre of a nitrogenous fertilizer material, such as nitrate of soda. Excess nitrogen may lessen their resistance to winter killing. An application of 8 to 10 tons of manure to which has been added 40 pounds of superphosphate to the ton will give excellent results. When manure is not available, apply 800 to 1000 pounds of a 4–12–4 or a 5–10–5 fertilizer to the acre. Superphosphated manure, or a complete fertilizer instead of a nitrogenous fertilizer material, should be used on very sandy soil. Unless manure is used, grow cover crops, and plow under as green manure to maintain the organic-matter supply of the soil. The same soil treatment should be given for currants, gooseberries, or other bush fruits.

**B. Apply lime only where soils are very acid.** Small fruits are not directly benefited by lime. In fact, strawberries and raspberries grow best on distinctly acid soils. Light applications of lime may be used for some of the small fruits if the soils are known to be very acid, but do not lime for raspberries or strawberries. Benefit will seldom if ever result, and actual injury may be brought about.

## GENERAL INFORMATION

### 1. Experimental Results in Fertilizing Orchards

The beneficial effect of nitrogenous fertilizer on a sod apple orchard twenty-five years old is shown in a striking manner by the results reported by the Connecticut Experiment Station.[4] On an average of three years, the application of nitrate of soda, at the average rate of 6⅔ pounds to the tree, produced an increase of 263⅓ bushels of apples to the acre. The untreated area yielded at the rate of 151⅓ bushels, and the treated section 414⅔ bushels to the acre.

[4] Conn. Agr. Exp. Sta. Bul. 87.

The failure of apple trees to respond to nitrogenous fertilizer, when grown on good soil properly tilled and with a cover crop grown annually, is shown in an equally striking manner by the results of an experiment at the Geneva Experiment Station, New York.[5] As an average of twenty-five years, a yield of 9088 pounds of fruit was secured without nitrogen, and 8719 pounds where an application of 100 pounds of nitrate of soda and 346 pounds of dried blood to the acre was made. In interpreting these results, Director U. P. Hedrick says:

> The practical outcome of the fertilizer test is that, in the average western New York apple orchard that is well cultivated, properly drained, and sufficiently supplied with organic matter and humus by means of a cover crop, commercial fertilizers are not needed.

## COMMUNITY STUDIES

1. Visit several well-managed fruit farms.
2. Study the soil-management practices followed for the different kinds of fruit grown.
3. What cover crops are grown in the orchards of the community, and which appear to give best results?
4. What are the fertilizer practices employed in sod orchards? In tilled orchards? Are they adequate?
5. Suggest possible improvements in the soil-management practices that have been observed in local orchards.

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Apple Growing in California. Calif. Bul. 425.
Farm Orchards. Wis. Cir. 265.

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[5] N. Y. Agr. Exp. Sta., Geneva, Bul. 516.

Fertilizing Deciduous Fruits. Calif. Bul. 610.
Fertilizing Fruit Trees with Nitrogen. Mo. Bul. 363.
Managing the Orchard. N. Mex. Bul. 168.
Orchard Cover Crops. Wash. Bul. 208.
Orchard Fertilization. Mich. Ext. Bul. 205.
Strawberry Production. Fla. Ext. Bul. 97.
Sweet Clover for Orchards. N. J. Cir. 269.

# APPENDIX

## The Agricultural Experiment Stations

Alabama—Auburn.
Alaska—College.
Arizona—Tucson.
Arkansas—Fayetteville.
California—Berkeley.
Colorado—Fort Collins.
Connecticut—Storrs.
Delaware—Newark.
Florida—Gainesville.
Georgia—Experiment.
Hawaii—Honolulu.
Idaho—Moscow.
Illinois—Urbana.
Indiana—La Fayette.
Iowa—Ames.
Kansas—Manhattan.
Kentucky—Lexington.
Louisiana—University.
Maine—Orono.
Maryland—College Park.
Massachusetts—Amherst.
Michigan—East Lansing.
Minnesota—Univ. Farm, St. Paul.
Mississippi—State College.
Missouri—Columbia.
Montana—Bozeman.
Nebraska—Lincoln.
Nevada—Reno.
New Hampshire—Durham.
New Jersey—New Brunswick.
New Mexico—State College.
New York—
State Station: Geneva.
Cornell Station: Ithaca.
North Carolina—
State College Station, Raleigh.
North Dakota—
State College Station, Fargo.
Ohio—Wooster.
Oklahoma—Stillwater.
Oregon—Corvallis.
Pennsylvania—State College.
Puerto Rico—
Federal Station: Mayaguez.
College Station: Rio Piedras.
Rhode Island—Kingston.
South Carolina—Clemson.
South Dakota—Brookings.
Tennessee—Knoxville.
Texas—College Station.
Utah—Logan.
Vermont—Burlington.
Virginia—Blacksburg.
Washington—Pullman.
West Virginia—Morgantown.
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